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Frontispiece

POWDERED COAL
AS A FUEL

BY

C. F. HERINGTON

Mechanical Engineer

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PREFACE

In placing this book before the engineering public, the author, who obtained much of the information herein presented while employed as Assistant Engineer in the office of the New York Central Railroad Company, wishes to give due acknowledgment for valuable aid rendered to the firms and individuals named below:

The Fuller-Lehigh Car Wheel and Axle Company
The Bonnot Company
The Ruggles-Coles Company
The General Electric Company
The Webster Mfg. Company
The Raymond Bros. Impact Pulverizer Company
The American Locomotive Co.
The Jeffrey Mfg. Company
The Aero Pulverizer Company
The Link Belt Company

Prof. R. C. Carpenter
Mr. A. A. Holbeck
Mr. H. Barnhurst
Mr. James Lord
Mr. J. H. Van Buskirk

Various patents, designs, and systems are here described, but the author wishes to emphasize the fact that comparisons have been made without bias and claims considered without prejudice. The underlying object has been not to advertise the advantages of any one system, but to show the merits of all.

C. F. H.

October, 1917.

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POWDERED COAL AS A FUEL

CHAPTER I

POWDERED COAL—INTRODUCTORY

Coal is the staple fuel of the metal-working industries because of its wide distribution and fairly stable price. It may be secured from several sources by almost every consumer and the coal industry is so widely controlled as to lead, generally, to favorable prices.

Powdered coal must compete with raw coal, fuel oil, and industrial gas. The elementary factor in such competition is the B.t.u. cost. If a gallon of oil containing 140,000 B.t.u. costs five cents, then the B.t.u. derived when one cent is spent for fuel oil will be 28,000. If powdered coal containing 14,000 B.t.u. per pound can be purchased for one-half cent per pound or ten dollars a ton, then there are 28,000 B.t.u. obtained for each cent expended to buy coal. The two fuels are then on a parity so far as B.t.u. cost goes, but any final analysis must consider also the comparative efficiencies in the furnace of the two fuels. If a cent's worth of coal will go farther; that is, last longer, or produce more, in a given furnace than a cent's worth of oil (even though both are represented by the same number of B.t.u.), then the coal is to be preferred.

Fuel oil fluctuates sharply in price and tends to become more expensive as demand increases. The same statement is true of natural gas. It is not true t like
the same extent for coal. Raw coal c l
with powdered coal with respect
With proper appliances and n

almost smokeless fire with a steady, intense heat and maximum furnace temperature.

It is true that the number of powdered coal plants is still small. Some of them have been in service for ten to fifteen years and these have fully demonstrated the feasibility and efficiency of a powdered coal installation. Fully 90 per cent of the Portland cement made in the United States is burned in kilns in which powdered coal is the fuel. The change from other fuels to powdered coal does not involve expensive furnace reconstruction. Any furnace adapted for fuel oil or gas may with slight changes be utilized for powdered coal.

The fuel to be used for pulverizing should be bituminous or semi-bituminous, either the slack or the run-of-mine. Coals rich in volatile matter are to be preferred. An advantage of slack over run-of-mine is that with the former no preliminary crushing is necessary. The following analysis represents a dried coal that has been found to give good results:

	Per Cent
Fixed carbon	54.00
Volatile matter	32.75
Ash	12.00
Moisture	1.25

GENERAL OPERATION OF POWDERED COAL PLANT

If not already in fine particles, the coal as received is crushed so as to pass through a $\frac{3}{4}$-in. ring. It is then dried in a direct-heat contact drier. The cost of the drying is appreciable, but this operation is absolutely necessary in order to permit of gool pulverizing. Usually the percentage of moisture is reduced to about 1.0. The expenditure of heat for the drying operation is not a net loss since no fuel of any kind ever burns in a furnace until the moisture contained therein has been evaporated.

Following the drying, the coal is pulverized in some one of the various types of grinder or mill, described in later chapters. It is made so fine that about 85 per cent will pass through a 200-mesh screen and about 95 per cent through a 100-mesh screen. A separating device is usually integral with the pulverizer. This carries off the finer particles while returning the grosser for regrinding.

The finely ground coal is now carried to bins from which it is fed to the furnace as required. The furnace construction and operation must be such that the lining remains continuously hot; which implies a steady, uniform feeding of the coal. This feeding must be under positive control, along with which must go a positive control of the air supply. The fire is started by lighting a piece of oily waste, placing it before the burner and turning on the coal. As is the case with fuel oil, the combustion is not very efficient until after the furnace is warmed up.

COMPARISON OF COSTS, FUEL OIL, WATER GAS AND PULVERIZED COAL

The following approximate figures are intended to show under the assumed conditions the relative costs for installation and operation of the three kinds of equipment named. It is assumed that there are 45 furnaces and that the heat consumption is 9,100,000,000 B.t.u. per month.

The assumed heat consumption is equivalent to 65,000 gallons of oil of 140,000 B.t.u. per gallon or to 650,000 pounds of coal at 14,000 B.t.u. per pound. For the gas plant it will be assumed that each cubic foot of gas contains 474 B.t.u. and that 20 cu.ft. of gas are produced per pound of coal. Then the coal consumption per month for making the gas is $9,100,000,00 \div (20 \times 474) = 960,000$ lb.

This corresponds with a gas-making efficiency of 0.68, which of course cannot be realized when only water gas is made. If, however, both producer gas and water gas are furnished from the same plant, the combined efficiency may be as high as that assumed. The producer gas will then be used for low-temperature work and the water gas in furnaces requiring high temperature.

1. *Fuel Oil, First Cost of Plant*

Three 10,000-gal. storage tanks at $850	$2,550.00
Unloading, excavation, and setting tanks	900.00
Two auxiliary pressure tanks in place	2,000.00
One circulating pump and motor	150.00
Piping, fittings and valves	5,000.00
Steam and air connections to tanks	1,500.00
Connections to furnaces, 45 at $50	2,250.00
Standpipes for tank cars	150.00
Pump and pump house	500.00
Blowers, motor and blast connections	5,000.00
Total	$20,000.00
Contractor's profit, 15 per cent	3,000.00
	$23,000.00
Engineering and contingencies—10 per cent	2,300.00
	$25,300.00

2. *Water Gas, First Cost of Plant*

Gas plant machinery erected in place	$45,000.00
Building, complete with foundations	20,000.00
Coal trestle, hoppers with siding	6,500.00
Gas piping, meters, valves, water piping	12,500.00
Changes in furnaces	4,000.00
Total	$88,000.00
Contractor's profit, 15 per cent	13,000.00
	$101,000.00
Engineering and contingencies, 10 per cent	10,000.00
	$111,000.00

With regard to the powdered coal plant, two types of apparatus will be considered. The first is that in which screw conveyor apparatus is used for distributing the coal, with individual bins, controls and feeders at each furnace. Another type of plant (see Chapter IV) is that in which the coal dust is carried to the various furnaces by means of low-

3. *Powdered Coal, Screw Conveyor Plant, First Cost*

Pulverizing machinery	$12,000.00
Buildings and foundations	6,000.00
Machinery foundations	2,000.00
Coal trestle and track siding	6,500.00
Conveyor system to the furnaces	11,500.00
Walkways and conveyor supports	6,000.00
Motors and wiring for conveyors	8,000.00
Burners and controllers for 45 furnaces at $250	11,250.00
Furnace changes, stacks	4,250.00
Furnace bins, 45 at $100	4,500.00
Hoods and exhaust system complete	6,000.00
Stack thimbles through roof	1,000.00
Total	$79,000.00
Contractor's profit, 15 per cent	12,000.00
	$91,000.00
Engineering and contingencies, 10 per cent	9,000.00
	$100,000.00

4. *Air Distributing System, Powdered Coal, First Cost*

Pulverizing Machinery	$12,000.00
Buildings and foundations	6,000.00
Machinery foundations	2,000.00
Coal trestle, etc	6,500.00
Spiral riveted pipe, fittings and valves	8,500.00
Furnace changes	2,500.00
Blowers, motors and wiring	8,000.00
Hoods and exhaust system complete	6,000.00
Total	$51,500.00
Contractor's profit, 15 per cent	7,725.00
	$59,225.00
Engineering and contingencies, 10 per cent	5,925.00
	$65,150.00

pressure air which conveys it in suspension from a central storage bin (Holbeck system).

Against these installation costs for the four types of plant, we now tabulate the annual operating costs, including fixed or overhead charges:

Operating Cost of Fuel Oil Plant

Fixed Charges:		
Interest, 5 per cent of $25,300	$1,265.00	
Depreciation, 10 per cent	2,530.00	
Taxes and insurance, 1 per cent	253.00	$4,048.00
Operation:		
Oil, 780,000 gal. at 4.6 cents per gallon	$35,880.00	
Labor, two men	2,000.00	
Electrical current, air and steam	720.00	
Repairs, 2 per cent of the cost	500.00	$39,100.00
		$43,148.00

Operating Cost of Water Gas Plant

Fixed Charges:		
Interest at 5 per cent of $111,000	$5,550.00	
Depreciation at 10 per cent	11,100.00	
Taxes and insurance, 1 per cent	1,100.00	$17,750.00
Operation:		
Coal, 5760 tons at $2.50	$14,400.00	
Labor, 1 operator and two assistants	2,800.00	
Unloading coal at $1.50 per car	200.00	
Cleaning generators	200.00	
Water	200.00	
Steam	200.00	
Repairs, 2 per cent, of $111,000	2,200.00	$20,200.00
		$37,950.00

Operating Cost of Powdered Coal Plant with Screw Conveyors

Fixed Charges:		
Interest, 5 per cent, of $100,000	$5,000.00	
Depreciation, 10 per cent	10,000.00	
Taxes and insurance, 1 per cent	1,000.00	$16,000.00

Operation:

Coal, 3900 tons at $2.50	$9,750.00	
Labor, 1 operator and two assistants	2,800.00	
Unloading coal at $1.50 per car	100.00	
Electrical current for motors	3,000.00	
Repairs, 2 per cent of cost	2,000.00	$17,650.00
		$33,650.00

Operating Cost of Powdered Coal Plant with Pneumatic Distributing System

Fixed Charges:

Interest at 5 per cent of $65,150	$3,257.50	
Depreciation at 10 per cent	6,515.00	
Taxes and insurance	651.00	$10,423.50

Operation:

Coal, 3900 tons at $2.50	$9,750.00	
Labor, 1 operator and two assistants	2,800.00	
Unloading coal at $1.50 per car	100.00	
Electrical current for motors	1,500.00	
Repairs, 2 per cent of cost	1,140.00	$15,290.00
		$25,713.50

SUMMARY

	First Cost.	Yearly Operation.
Fuel oil plant	$25,300.00	$43,148.00
Water gas plant	111,000.00	37,950.00
Powdered coal plant (screw conveyor)	100,000.00	33,650.00
Powdered coal plant (pneumatic)	65,150.00	25,713.50

More briefly still, we have the following:

	Operating Cost per Ton of Coal Burned.	B.t.u. Delivered to Furnace per 1 Cent of Operating Cost.
Fuel oil	....	25,300
Water gas	$6.60	28,700
Powdered coal (screw conveyor)	8.65	32,500
Powdered coal (pneumatic)	6.59	42,

CHAPTER II

COALS SUITABLE FOR POWDERING

POWDERED coal weighs 38 to 45 lb. per cubic foot, although the solid particles have a specific gravity between 1.3 and 1.35. The free surface of a pile at rest makes an angle of 34 to 38 degrees with the vertical, if dry. These properties do not vary much with the grade of coal.

EXPERIENCE WITH VARIOUS GRADES OF COAL

The impression has prevailed until recently that only bituminous coals were suitable for powdering.

Bituminous, or soft coal, differs from anthracite in its greater proportion of volatile content. The greater the percentage of volatile constituents in coal, the more readily will it deflagrate. These volatile gases distill from the fuel and ignite at a temperature much lower than that required for carbon itself. To burn them requires a greater relative supply of oxygen than that necessary for carbon. Their average heat value is nearly 50 per cent greater than that of carbon.

The fuels available for burning in Portland cement kilns may have a wide range of quality. The best bituminous coals are preferable, but those of poor quality are occasionally found in successful use. The fuels used in the Eastern portions of the country are generally obtained from the soft coal mines of Pennsylvania and Maryland, Virginia and West Virginia. The coals employed in mills in the West are those most accessible from the plant and cheapest in price on the heat unit basis.

The effort to use low-grade coal has been at once one of the most attractive and elusive features of powdered coal firing. Unsuitable coal, while not always the ultimate cause of failure, has often been the immediate cause for the discontinuance of experiments. While it is possible to burn inferior grades of coal in powdered form, there are often so many complications introduced as to overcome any economy. The idea of using up the extensive anthracite culm piles may have to be abandoned. The particular difficulty with low-grade coals is in the disposal of the slag. Average slag moves very sluggishly at a temperature of 2500° F., and practically all slag solidifies at 1800° or above.

As a single example of the effect of low-grade coal, Mr. W. A. Evans, in a discussion before the Western Engineers' Society, quotes his experience with a malleable iron annealing furnace. "Coal containing about 4 per cent of ash was being used with very satisfactory results. Exact control of the heat was possible throughout the annealing process. A very small amount of slag was deposited in the combustion chamber on a bed of cinders, and this was easily removed every twenty-four hours. One of the officers of the company compared the appearance of the fine powder with that from a cheap slack coal that could be bought for about half what the good coal was costing, and he insisted upon the use of the cheaper coal. It did not take long to demonstrate the unavailability of the substitute. Slag deposited rapidly in the combustion chamber and frequent opening of the furnace front was made necessary in the effort to remove it. The result was that the furnace would cool down. The saving in cost of fuel was soon overcome by complications and ruined castings."

It is desirable to use the very best coal obtainable, when working out a new problem. The trial of cheaper coal can be undertaken when other details have been perfected.

EXPERIMENTS

In the Engineering and Mining Journal of 1876, Chief Engineer B. F. Isherwood, U.S.N., described a test made by naval engineers under his direction in 1867 and 1868 at

South Boston, Mass., with both anthracite and semi-bituminous coals, in commercial and powdered forms. The highest rate of combustion attained was 13.8 lb. per square foot of grate per hour for the anthracite and 14.9 lb. for the bituminous, referring all coal, powdered as well as solid, to the grate area. Mr. Isherwood's conclusions were that, including the cost of pulverizing, the anthracite did a great deal better and the semi-bituminous a little better, when burned upon the grate in the ordinary way, than when burned in the powdered condition.

The powdered coal used under a Bettingdon boiler which gave an efficiency, under test, of 82.6 per cent, contained 2.15 per cent of moisture, 22.8 per cent of volatile matter, 57.55 per cent of fixed carbon and 17.5 per cent of ash. A number of these boilers (see Chapter VIII) are in use in South Africa, Great Britain and Canada.

For metallurgical furnaces, the practice of the American Iron and Steel Co. of Lebanon, Penn., indicates that the volatile content should be not less than 30 per cent. A typical coal used by them analyzed 1.12 per cent moisture, 33.2 per cent volatile, 56.07 per cent fixed carbon and 9.61 per cent ash. The American Locomotive Co., at Schenectady, N. Y., uses in its drop forge furnaces a coal high in volatile matter, low in ash, and dried until it contains not over ½ of 1 per cent of moisture. In a reverberatory furnace, the Canadian Copper Co. employs a good quality of slack. Analysis of one lot showed: volatile matter, 34.70; fixed carbon, 55.40; ash, 9.45; sulphur, 1.30; moisture, 4.31 per cent. This coal has a thermal value of about 13,500 B.t.u. per pound.

One of the most severe tests yet made was with a semi-bituminous coal from Brazil, analyzing as pulverized:

	Per Cent.
Moisture	from 2- 8
Volatile	from 14–28
Fixed carbon	from 58–34
Ash	from 26–30

The sulphur averaged from 3 per cent to 9 per cent and the B.t.u. from 10,900 to 8,800. No difficulty whatever was experienced, according to Mr. J. E. Muhlfeld, in maintaining maximum boiler pressure when working a locomotive with this fuel under the most severe operating conditions. The ash and sulphur contents in this instance are strikingly abnormal and adverse to good operation. A more usual coal for locomotive practice is mentioned by Mr. Muhlfeld as having been employed on an Atlantic type passenger locomotive. This was a Kentucky unwashed screenings testing 2.46 per cent moisture, 36.00 per cent volatile, 54.00 per cent fixed carbon, 0.78 per cent sulphur and 7.94 per cent ash. It contained 13,964 B.t.u. per pound.

In Muhlfeld's experiments on locomotives, described in the Journal of the American Society of Mechanical Engineers for December, 1916, mixtures ranging down from 75 per cent run-of-mine bituminous and 25 per cent anthracite birdseye (over $\frac{1}{16}$ in. and through $\frac{5}{16}$ in.) to 40 per cent of the former with 60 per cent of anthracite culm, were burned with equally satisfactory results. The average composition of the coals referred to is shown in the following table:

Item.	PULVERIZED.		
	Bituminous Run-of-Mine.	Anthracite.	
		Birdseye.	Culm.
Moisture, per cent	0.50	0.50	1.00
Volatile, per cent	29.50	7.50	6.00
Fixed carbon per cent	60.00	77.00	71.00
Ash, per cent	10.00	15.00	22.00
Sulphur, per cent	1.50	1.00	2.50
B.t.u. per pound	13,750	12,750	11,250
Fineness, per cent through 200-mesh	86.00	86.00	

Satisfactory results are also reported
lignite having an analysis of: moistu

volatile, 47.0 per cent; fixed carbon, 41.0 per cent; sulphur, 0.75 per cent; ash, 9.5 per cent; with a heat value of 10,900 B.t.u. per lb.

Mr. Muhlfeld claims that the use of powdered anthracite culm will double the steam-generating capacity of stationary boilers now burning birdseye anthracite, hand-fired on grates; and at the same time eliminate fire cleaning, greatly decrease the amount of ash to be handled, and reduce the boiler-plant-labor cost about 40 per cent. He has employed birdseye containing 7 to 9 per cent volatile and 19 to 22 per cent ash, and culm containing 6 to 10 per cent volatile and 22 to 46 per cent ash, in tests on a 463 horsepower Stirling water-tube boiler, with the following results:

Test No.	1	2	3	4	5	6	7
Duration, hours	72	336	24	48	120	240	24
Horsepower rating	463	463	463	463	463	463	463
Horsepower developed, %	133	135	147	178	112	118	124
Fuel:	Anth.	Anth.	Anth.	Anth.	Anth.	Anth.	Anth.
Kind	B'eye	B'eye	B'eye	B'eye	Culm	Culm	Culm
Dryness, per cent	0.65	0.65	0.65	0.65	0.8	0.8	0.8
Fineness, per cent through 200-mesh	86.0	86.0	85.0	86.0	88.0	86.0	88.0
Evaporation, from and at 212° F., lb	8.7	8.9	9.6	9.8	7.8	8.1	8.5
CO_2, average per cent	16.6	16.3	15.9	16.6	1.62	16.5	16.7
Vacuum in breeching uptake, in. of water	0.25	0.23	0.22	0.23	0.27	0.28	0.27
Vacuum in combustion chamber, in. of water	0.16	0.14	0.13	0.16	0.17	0.19	0.15
Boiler pressure, average lb	140	142	141	140	143	144	145
Flue-gas temperature, deg. F., average	518	525	496	603	475	580	576

SUMMARY

Most of the experience hitherto obtained has been on high grade, highly volatile, soft coals, and efforts to burn inferior grades have often led to disappointment. It is in recent practice, and in the hand of only a few investigators, that good results have been obtained from inferior soft coals and from anthracite. All of the most recent developments for steam generation have been made with anthracite culm, at one time definitely abandoned as a suitable fuel for powdering. Powdered coal, like ordinary commercial coal, should be practically free from sulphur, for all but the most exceptional applications.

THE ASH QUESTION

The presence of inert impurities in the fuel has not much effect. Only combustibles will burn; the combustibles, if inert, do not necessarily affect the operation of the furnace. Their effect is in the reduced amount of useful work obtained from a dollar's worth of fuel. Coal has been burned which contained up to 52 per cent of ash. Good performance depends not so much on the per cent of ash or the heat value of the fuel as upon dryness, fine grinding, a hot fire box and proper air supply. One authority goes even so far as to say that any solid fuel that, in a dry pulverized form, has two-thirds of its content combustible, is suitable for steam-generating purposes. "Domestic and steam sizes and qualities of anthracite, bituminous, and semi-bituminous coals, and lignite and peat, as well as the inferior grades such as anthracite culm, dust and slush, and bituminous and lignite slack, screenings and dust, are all suitable for burning in pulverized form."

But while the absolute *amount* of ash in coal may have only minor influence on its suitability for use when powdered, the *quality* of the ash is all-important.

With the ordinary method of burning coal under a steam boiler, the grate (with its bed of solid incandescent fuel more or less encumbered with ash and clinker) offers a considerable, a varying and an irregularly distribut
ance to the passage of air, rejects the incombustib
with some difficulty and allows some of the u
to sift to the ashpit or to be fused in with the

powdered coal, burned in suspension, many of these difficulties disappear. There still remains, however, the difficulty of getting rid of the incombustible. With 10 per cent of ash there will be 200 lb. of refuse to be disposed of, for each ton of coal burned. If this ash is kept in a pulverized form it is carried into the back connection, the tubes and stack, and scattered about the neighborhood. If it is *fused*, an even more serious difficulty may arise. The clinker then attaches itself to the surface of the furnace and welds itself into large masses. This may occasion damage to the brickwork when the clinker is removed and necessitates comparatively frequent lay-offs for cleaning. In one instance, the molten slag formed in ridges and sheets upon the sides and in stalactites upon the roof of the furnace, while the floor was covered with a plastic mass, which cooled when the door was opened for its removal, and could scarcely be withdrawn without material damage to the furnace.

According to Muhlfeld, clinker is of two kinds: "hard" and "soft." "Hard clinker" is formed by the direct melting of some of the ash content. It hardens as it forms and usually gives but little trouble. "Soft clinker" is formed by the slagging of the ash and is either pasty or fluid and steadily grows in size. "Honeycomb" or "flue-sheet clinker" is formed by the condensation or coking of tarry matter or vapor as it strikes against the fire-box sheets, and results in the accumulation of a relatively soft, light, ashy substance that grows or spreads over certain of the refractory or metal parts of the furnace.

A common source of trouble is the ferric sulphide (iron pyrites, FeS_2) in the ash. This is reduced to ferric sulphide (FeS) in the furnace. The latter substance melts at about 2300° F. and forms a pasty mass. If subjected to high heat and an excess of air, it forms Fe_2O_3, ferric oxide, which combines with the silica present in the ash to form a relatively harmless infusible clinker. If the supply of oxygen is insufficient, on the other hand, the ferric sulphide becomes ferrous oxide, FeO, which when combined with silica produces the troublesome honeycomb. Proper adjustment of combustion conditions to suit the fuel used will therefore help to mitigate clinker difficulties. Generally speaking, silica, alumina and magnesium decrease the fusibility of ash; while iron, lime, potassium and sodium tend to increase its fusibility.

The ash question is usually less serious in metallurgical applications. At the furnace of the Canadian Copper Co., referred to in Chapter VI, the ash from the coal causes very little trouble in operation. A small amount settles on the slag, but as the ash contains considerable amounts of iron, this is not an undesirable feature. A small quantity also settles in the flue and a few hundred pounds may stick around the throat. Where exposed to high heat, the ash forms a very light pumice-like fragile mass. The throat is cleaned out daily by opening the door under the flue. During the cleaning the firing is maintained as usual.

The possible influence of coal composition on the analysis of furnace product is suggested in the following table, which compares results obtained in the same furnace with fuel oil and powdered coal:

Analysis of Slag.	Per Cent.	
	Oil.	Coal.
SiO_2	16.0	16.5
FeO	22.0	18.2
MnO	7.4	6.7
P_2O_5	1.7	1.9
Final analysis of the steel:		
Sulphur	0.025–0.035	0.035–0.04
Sulphur in coal	1.0–1.15	

There appears here to be no more difference than would naturally occur daily from variations of charge and fuel.

In the experience of the General Electric Company, Schenectady, N. Y., with a wide range of metallurgical op tions, slag and clinker gave no especial difficulty. In steam generation, they became serious factors only under heavy boiler loads, say 40 per cent above normal, and indicated the necessity of care in designing and operating boiler furnaces. "With powdered coal, furnace temperatures are high; 2700° F. or more is not uncommon and most of the ash will slag when hot. It was aimed at Schenectady to slag as much as possible, drawing off the fused product at intervals. Fine ash passes on among the tubes. The slag weighs 5.72 per cent and the soot 3.41 per cent of the coal that made it. This coal gives 11.26 per cent of ash in the laboratory, so that 2 per cent must have gone up the stack. This 2 per cent is a very fine white powder, scarcely visible at the chimney top. The slag, which weighs 114 lb. per ton of coal fired, contains no carbon whatever. At moderate loads, say up to 180 per cent of normal, it is drawn out once during the day to a concrete pit containing water. The pit is cleaned out with pick and shovel the next morning. This is not the easiest way to handle slag. If there were a cellar beneath the boiler room there would be less labor, but even as it is the work is not difficult. Water in the pit is essential however.

"With heavy loads, some particles of slag travel with the gas current and cling to the first cold surface they meet; that is, to the bottom row of tubes. If this slag is allowed to accumulate for ten hours, it will choke off enough of the gas passage to make reduction of load necessary. This was a great difficulty at first, but it has been overcome. The accumulation can be blown off with a steam jet once during the forenoon and again in the afternoon. This does not call for much time and is not laborious. Further improvement has been made by admitting a little steam at the inlet end of the gas passages. This steam travels with the hot air, mingling with it and altering the character of the fire; it makes slag run more freely, softening and decreasing the quantity that clings to the tubes. It pays to blow tubes once a day. Most of the soot goes over through the second pass of the boiler and drops in the back chamber. The bottom of that chamber has been paved, giving it a pitch, with a drain pipe leading to a pit, and all this material is washed out every second day by merely opening a valve. The soot, however, is a loss; for 60 per cent of it is carbon; that is, 60 per cent of 3.41 per cent or 2 per cent of the coal is unburned. The soot is light and fluffy, weighing 18 lb. per cubic foot. No good use for it has been found thus far."

Trouble from ash in metallurgical operations may arise in the combustion chamber, on the hearth, or in the flues. In the combustion chamber, slag can be provided for by the use of a bed of cinders, which will remain loose and can be pried out. On the hearth of a reverberatory furnace the ash forms a slag which can be drawn off with other impurities. In the gas flues, control of the heat should be such as to keep the temperature too low to permit the formation of slag. In any case, frequent and easy access should be given for cleaning. Checker work is, according to one authority, entirely unsuitable for the use of powdered coal. It will slag up and become inoperative.

In locomotive applications, the liquid ash runs down the under side of the main arch and the front and sides of the forward combustion zone of the furnace and is precipitated into the self-cleaning slag-pan. Here it accumulates and is air-cooled and solidified into a button of slag which can be dumped by opening the drop bottom doors.

SUMMARY

Ash disposal presents problems different from those encountered with ordinary coal. They are to be handled by proper selection of fuel (giving attention to the composition of the ash), by control of combustion, by running off liquid slag and by the mechanical or manual cleaning of surfaces where powder or clinker may accumulate.

CHAPTER III

PREPARATION OF POWDERED COAL

HAVING selected a proper grade of coal, usually one containing in the neighborhood of 30 per cent of volatile matter, the first operation is generally a crushing to about 1-in. size.

Fig. 1 shows the Jeffrey single roll crusher. It is so constructed as to withstand the severe usage to which it is likely to be subjected, being built for strength and endurance rather than with any over-refinement of parts.

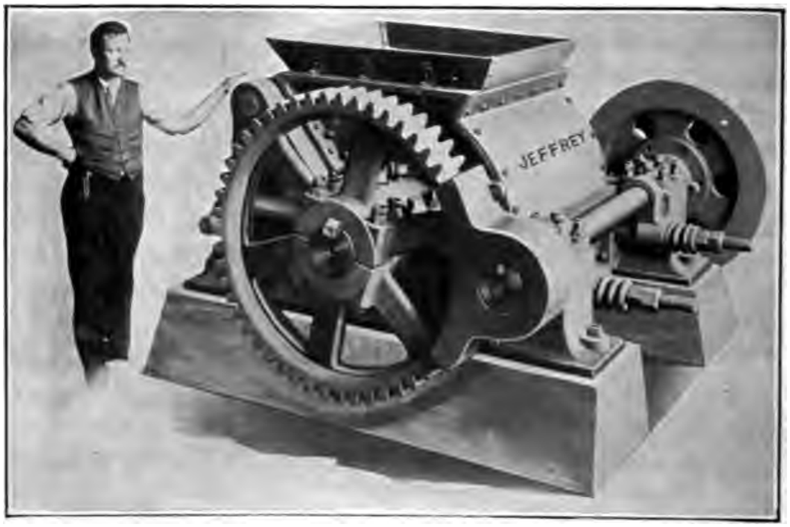


FIG. 1.—Jeffrey Single-roll Crusher.

The machine consists of a heavy cast-iron frame, in which are mounted a crushing roll and a breaker plate. The breaker plate is hinged at its upper end and is held in position by a pair of adjusting rods at the lower edge. By this means the clear opening between the breaker plate shoe and the surface of the roll can be varied to give any size of product required.

A clamping effect is produced by proper adjustment of the cross-rod bolts between the side frames, whereby sufficient friction may be brought upon the hinged breaker plate to eliminate chattering and to assist the safety device.

The concave breaker plate acting in conjunction with the roll makes a form of maw, with a very small angle of repose; hence the machine will readily grip a large lump and reduce it to such size as will pass through the opening between the roll and plates. A countershaft, mounted directly on the machine, drives the roll through a pair of gears. These are made so heavy that sufficient torque is obtained to start the roll under all conditions of load. The machine cannot become overloaded or clogged up under any volume of coal. It makes the entire reduction in a single operation.

The driving pulley is not keyed to the shaft, but is mounted on a separate hub which it drives through a set of wood pins inserted in holes in the arms of the pulley. When any undue strain comes on the machine from any cause, these wood pins shear off, and the roll stops while the pulley keeps on revolving. There is thus formed an efficient safety device preventing accidents to workmen. After the cause of the trouble has been removed, new wood pins put the machine again in operative condition.

A pair of heavy springs is placed on the tension rods. These springs do not move under ordinary working conditions; but when an undue pressure comes on the breaker plate, they act as a cushion, yielding slightly, taking up the inertia of the parts and allowing time for the pins to shear without breaking more important elements of the machine.

Fig. 2 shows the "S–A" improved coal crusher, fitted with the patented toggle spring release, which gives maximum pressure between the rolls when they are in normal operating position. On the ordinary spring type of crusher the pressure is weakest when the rolls are in normal operating position. The two types of crusher operate in exactly opposite ways. Since the pressure between the rolls decreases as the rolls are separated, pieces of iron or other hard material will not injure the rolls of the "improved" type of crusher as they do the rolls of the ordinary machine. The pressure between the rolls is regulated by nuts that are easily accessible.

Following the crushing, the coal may be carried (often by belt conveyor and elevator) to a magnetic separator like the Ding "magnetic pulley," which removes any iron or steel scrap, nuts, pick points, pieces of iron, bolts, etc., that would interfere with pulverization.

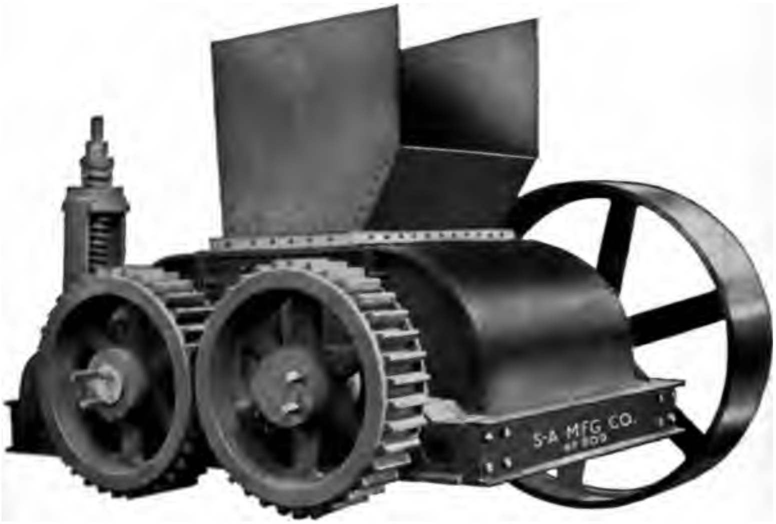


FIG. 2.—S-A Improved Coal Crusher.

The coal, before pulverizing, should be well dried, down to 1 per cent or less of moisture. This makes it pulverize better and burn more freely. Coal does not grind well if moisture in excess of this is present. Nothing is lost by drying it separately. In burning coal, the moisture, free or combined, must be disposed of either in the process of preparation or at the moment of combustion. In the latter case, not only is the efficiency of the furnace lowered by the calorific investment in the superheated steam passing out as a product, but the temperature of the furnace is lowered materially. Drying wet coal in the furnace itself is doing this necessary part of the work in the most expensive place and at the sacrifice of temperatures which may be essential to the industrial process.

In the practice of the American Iron and Steel Co. (see Chapter VII), attention has been given the possibility of using undried coal. In all cases, it was finally deemed best to provide for drying. The drying equipment may be arranged for intermittent use, if apparatus of standard size is too large for the required quantity and moisture condition of the coal available.

First cost so often enters into the selection of apparatus that a number of plants without dryers have been introduced with fairly good results, maintained even when the coal contained as much as 15 to 20 per cent of water.

Mr. Lord of the American Iron and Steel Co. described a visit to an installation in Iowa at a time when there was deep snow on the ground. Into this snow the coal was shoveled after dynamiting it out of the car. It was then elevated, snow and all, to the coal hoppers over the pulverizing machines. There was never any difficulty in the operation nor any trouble in maintaining the flame, but the procedure was certainly not favorable to good economic results. It was estimated that about 20 per cent more coal was used in the furnaces than would have been consumed with adequate drying facilities: and the power consumption for pulverizing was considered to be about 50 per cent in excess of normal.

The only reason for using wet coal is the desire to keep down the initial investment; and even at that, says Mr. Lord, there must exist the assurance of commercially dry coal for the greater part of the time, i.e., coal carrying moisture under 5 per cent. Provision should be made for protection from the weather as much as possible both at the plant and in transit. One concern ships its coal in box cars. Storage will drain off some moisture, but slack coal will retain 15 per cent of moisture indefinitely, unless stirred up and brought in contact with air.

Where wet coal is used, and in all low-temperature applications, an igniting flame must be provided. In the installation just referred to this is accomplished by a grate fire in a steel box 18 in. square and 5 ft. long, and 12 in. square inside the brick lining. The powdered coal blowing through this small box comes in contact with the grate fire flame and hot brick walls and ignites readily. The coal on this grate is replenished by particles dropping from the powdered coal as it blows through. The powder which falls on the grate forms coke and burns freely. Attention is required only once in twenty-four hours for cleaning and raking out.

The possible elimination of the dryer is further limited to those cases where a type of grinding machine is used that will handle moist coal. Pulverizers using screens for the separation of the coarse and fine material clog up immediately when fed with moist coal.

THEORY OF DRYING

To dry a stated weight of any material a definite number of heat units must be used; first, to raise the temperature of the material to 212°; second, to raise the temperature of the total amount of water contained in the material to 212°; and third, to evaporate such part of the water as may be desired. The total number of heat units may be calculated from the specific heat of the material, the initial and final percentages of moisture and the initial temperature.

If then the heating value of the fuel used for drying and the thermal efficiency of the apparatus are known, the quantity of fuel required for any capacity may be determined.

When the composition of fuel is known, we may then compute how much air is theoretically needed to burn it. The resulting temperature of combustion, however, would be much too high for dryer operation. A large excess of air must be introduced, to bring the temperature of gases down to about 1400° F., at which temperature they enter the gas passage of the dryer. This comparatively high temperature is quickly reduced by the transfer of heat through the steel shell to the drying coal. When these gases have reached the delivery end they may be at a temperature of about 250° F. If (as in some forms of machine) they then pass back through the cascading coal, they are still further reduced in temperature, and may finally leave the fan at about 100° F. In cooling, the gases are greatly reduced in volume; so that the velocity through the shell is decreased to such a point that comparatively little dust is carried off.

Indirect-fired Rotary Coal Dryer. The Fuller-Lehigh indirect-fired coal dryer (Fig. 3) consists of an axially inclined cylindrical shell fitted with rollers and gearing

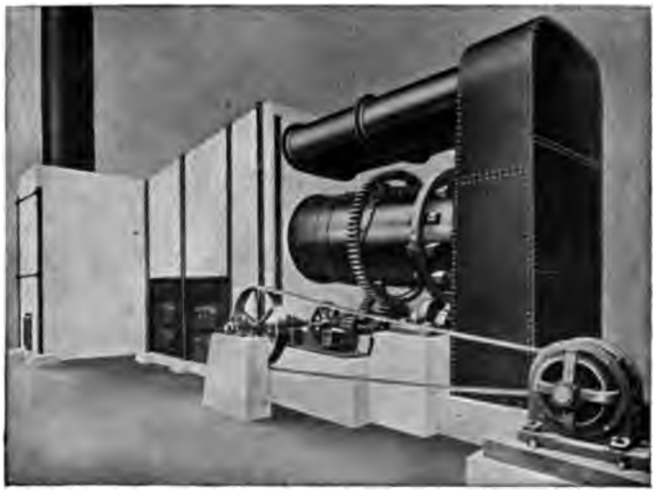


FIG. 3.—Fuller-Lehigh Indirect-fired Dryer.

which rotate the shell on its longitudinal axis. The higher end of the dryer shell terminates in a brick housing which serves to support the stack required to discharge the wast products of combustion of the dryer furnace, including t water vapor given off by the moist coal. The furnace for heating the dryer is placed between the stack chamber and the hood. The furnace may be provided with a large combustion chamber through which the dryer shell passes. The entire furnace is built of brick and the walls are securely bound together by means of buckstays and tie rods.

The moist coal is fed into the dryer shell through a feed spout located in the stack chamber. This spout enters the dryer shell and delivers the coal close to the bottom. A series of longitudinal shelves fastened to the inside of the dryer shell lifts the coal and drops it through the current of heated air passing through the inside of the dryer shell. Since the revolving shell of the dryer is slightly inclined downward toward the discharge end, the coal travels the entire length of the shell and is finally discharged from the lower end.

The hot gases from the furnace circulate around the outside of the dryer shell, passing through the combustion chamber of the furnace. They then leave the combustion chamber through the horizontal breeching and enter the top of the hood at the lower end of the dryer. From this hood the hot gases flow to the interior and come in direct contact with the coal in the dryer shell. After they pass through the interior, the hot gases enter the stack chamber at the upper end of the dryer, and then escape to the atmosphere through the stack.

No flame comes in direct contact with the coal being dried, and there is absolutely no possibility of the coal's taking fire during its progress through the dryer shell. No fans are used in connection with this type of dryer, as the stack draft is sufficient to move the gases at the required velocity.

Ruggles-Coles Dryer. This form of dryer, illustrated in Fig. 4, consists of two long concentric steel plate cylinders which are set with the delivery end slightly lower than the head end. Between the inner cylinder, which acts as a flue for the hot furnace gases, and the outer shell is the space which holds the material to be dried. The two cylinders are rigidly connected midway between the ends, and by placing swinging arms between this center and each end, allowance is made for the unavoidable expansion and contraction due to differences in temperature. Such construction entirely prevents the shearing of rivets or loosening of joints.

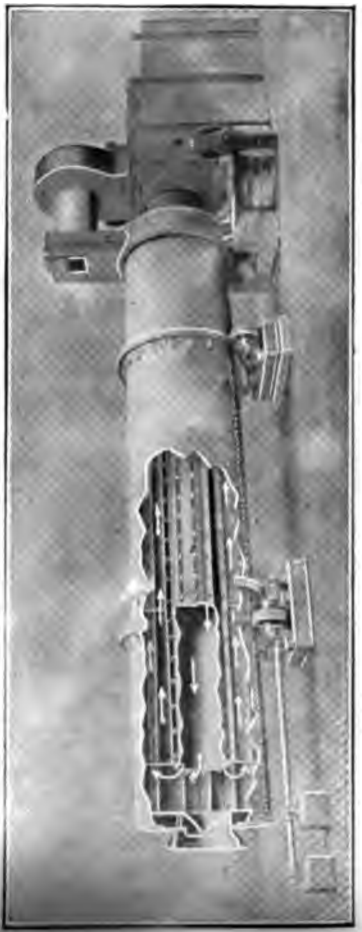


FIG. 4.—Ruggles-Coles Dryer.

The dryer is supported on two steel tires which are rigidly riveted to the outer cylinder. Each tire rests on four bearing wheels made of chilled iron. These are arranged in pairs on rocker arms, which are supported on heavy cast-iron bases. Two large thrust wheels are provided on one of the bases to hold the cylinder tires against the wheels. Set screws allow the bearing wheels to be adjusted while the machine is in operation, so that tires can ride centrally on them without exerting pressure on the thrust wheels.

Distribution of the weight of the dryer on eight bearing wheels, each of which has two bearings, prevents excessive wear or overheating. Riveted to and around the outer cylinder [illegible] gear which engages with a pinion keyed to the [illegible] shaft. This shaft may be located on either side or [illegible] of the dryer, as may best suit local conditions.

Lifting plates are fastened to the inside of the outer shell, running parallel with the axis of the dryer for its entire length. The revolving of the dryer causes these plates to lift the coal and drop it on the hot inner shell. By the inclination of the dryer the coal is carried from the feed end to the delivery end. On the inside of the discharge head at the delivery end there are riveted buckets which discharge the dried coal through a central delivery casting. At the feed end the inner cylinder extends beyond and through the stationary head and connects directly with the flue from the furnace. This inner cylinder forms an extended combustion chamber for the unconsumed gases leaving the furnace. Doors are provided at both ends of the dryer for inspection purposes.

Following the drying, the coal is pulverized to its final degree of fineness. With the best type of machines obtainable for this purpose, the coal and its contained impurities may readily be powdered to such a degree that under screening tests 85 to 90 per cent will pass through an aperture $\frac{1}{200}$-in. square, while the total residuum left upon a screen whose apertures are $\frac{1}{200}$-in. square will be only from 2½ to 5 per cent; and even this residuum would pass through screens $\frac{1}{100}$-in. square. It must be borne in mind that of the quantity passing the apertures $\frac{1}{200}$-in. square there is a high percentage of absolute dust or impalpable powder not commercially measurable. This is proven by the fact that in tests made upon calibrated screens of $\frac{1}{300}$-in. square aperture, over 70 per cent still passed through. It is certainly safe to assume, therefore, that the average volume of particles will be less than that of a cube measuring $\frac{1}{300}$-in. on the side. No determination is made, usually, of fineness below 200-mesh.

The total number of particles resulting fron the powdering of 1 cu.in. of coal to spheres $\frac{1}{200}$ in. in diameter is over 15 million. Simple calculation on this basis shows that while a cubic inch of coal exposes 6 square *inches* for absorption and liberation of heat, the surface exposed for the same purpose by the powdered coal is over 8 square *feet.* Since no fuel burns until it is heated to the temperature at which it develops more heat than it receives, the advantage of this enormous absorbing and delivering surface is apparent. The result of this is shown in the clearness and uniformity of the flame produced. Where coarse particles are permitted to enter the furnace, distinct sparkles are apparent. These larger particles are carried beyond the region of oxygen supply and are for this reason not fully burned.

At the Anaconda plant (see Chapter VI) the grinding is done so that from 93 to 97 per cent will pass through 100-mesh and 79 to 82 per cent through 200-mesh. Coals of high specific gravity will grind finer in an impact pulverizer. In cement work, there is no gain by grinding finer than 95 per cent through 100-mesh. This gives from 75 to 85 per cent through 200-mesh, the percentage depending upon the physical character of the coal. Coal thus pulverized will contain a high percentage of fine dust practically unmeasurable. As there is no difficulty in burning coal thus prepared, there seems to be no good reason for pushing pulverization beyond this point. Coal can be brought to this condition quite cheaply, and the mills able to so this work have large capacity. Higher percentages may be obtained by the sacrifice of capacity, and consequently of grinding economy. The standard of approximately 85 per cent through 200-mesh and 95 per cent through 100-mesh is a practicable commercial standard and should be maintained.

Fuller-Lehigh Pulverizer Mill. In this mill (Fig. 5) the coal is fed from an overhead bin by means of a feeder mounted on top of the mill. This feeder is driven direct from the mill shaft by means of a belt running on a pair of three step cones, which permit operative adjustment. In addition, the hopper of the feeder is provided with a slide, which permits the operator to increase or decrease the amount of coal entering the feeder hopper.

The coal leaving the feeder enters the pulverizing zone of the mill. The pulverizing element consists of four unattached steel balls which roll in a stationary, horizontal, concave-shaped grinding ring (Fig. 6). The balls are propelled around the grinding ring by means of four pushers attached to four equidistant horizontal arms forming a portion of the yoke, which last is keyed direct to the mill shaft. The material discharged by the feeder falls between the balls and the grinding ring in a uniform and continuous stream, and is reduced to the desired fineness in one operation.

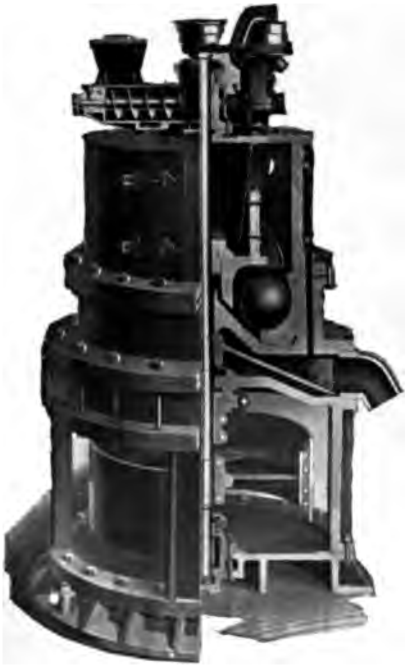


Fig. 5.—Fuller-Lehigh Pulverizing Mill.

Those mills which operate with fan discharges are fitted with two fans. One of these fans is connected in the separating chamber immediately above the pulverizing zone, and the other fan operates in the fan housing immediately below the pulverizing zone. The upper fan lifts the fine particles of coal from the grinding zone onto the chamber above the grinding zone, where these fine particles are held in suspension. The lower fan acts as an exhauster, and draws the finely divided particles through the finishing screen which completely encircles the separating chamber. The coal leaving the separating chamber is drawn into the lower fan housing, from which it is discharged through the discharge spout by the action of the lower fan. All of the coal discharged from the mill is finished product and requires no subsequent screening.

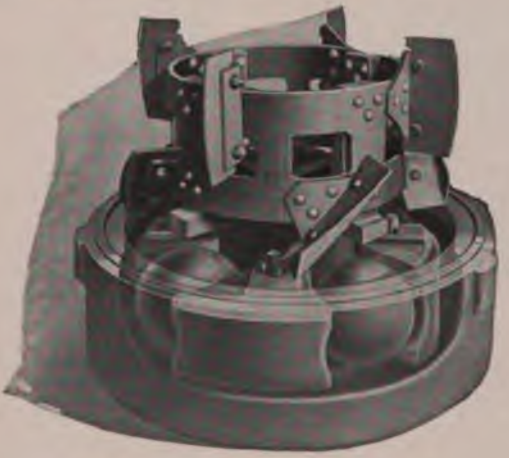


FIG. 6.—Fuller-Lehigh Grinding Ring.

The current of air induced by the action of the lower or discharge fan passes over the pulverizing zone, and out through the screen surrounding the separating chamber, thus insuring cool operation and maximum screening efficiency. This current of air keeps the screen perfectly clean and enables the mill to handle coal containing a considerable amount of moisture.

When the mill is in operation, it is handling only a limite amount of coal at any one time. As soon as the coa reduced to the desired fineness, it is lifted out of the verizing zone and discharged. As the crushing is applied to only a limited amount of coal, the power required to operate the machine is reduced to a minimum. Furthermore, this power is applied directly to the coal being pulverized.

In order to insure steady operation, every mill should be provided with a storage bin of capacity not less than four to six times the hourly capacity of the mill. Each bin should have a chute or feed pipe, 6 or 8 in. in diameter, to permit the coal to flow from the bin to the hopper of the mill feeder. This chute should be provided with a gate or cut-out slide placed close to the bin so that the flow of coal through the chute may be controlled.

A platform should be provided around the mill so that the operator may have easy access to the feeder. The floor of this platform should be about 3 in. below the top flange of the intermediate section. A small volume of air is discharged from the mill with the finely pulverized coal. An air chamber should therefore be provided in connection with the conveyor taking the coal away from the mill, to permit the free escape of the air. The size of the air chamber varies with the size and number of the mills discharging into the conveyer. The air chamber should be proportioned so that an area of cross-section of 1 sq.ft. is provided for a 33-in. mill and of 1½ sq.ft. for a 42-in. mill. A vent pipe about 10 in. in diameter should be placed on top of the air chamber. This vent pipe may be connected with a suitable collecting chamber to prevent loss of dust from this source.

In order to facilitate the erection of the mills and the renewal of worn parts, it is advisable that some form of hoist be placed above the mill. These hoists should have a capacity of three (3) tons for the 33-in. mill, and four (4) tons for the 42-in. mill. These mills are capable of grinding coal to a fineness such that at least 95 per cent will pass through a 100-mesh screen.

Raymond Bros.' Impact Pulverizer. The Raymond roller mill (Fig. 7) crushes and grinds coal by gravity and centrifugal force. At the top of the main shaft is a rigidly attached spider which rotates with the shaft. To the arms of this the rollers are pivotally suspended by trunnions carried in bearings in the roller housing. Both upper and lower bearings of the roller journals within the [illegible] housings are provided with long removable phosphor [illegible] bushings. The rollers are made of cast iron [illegible]

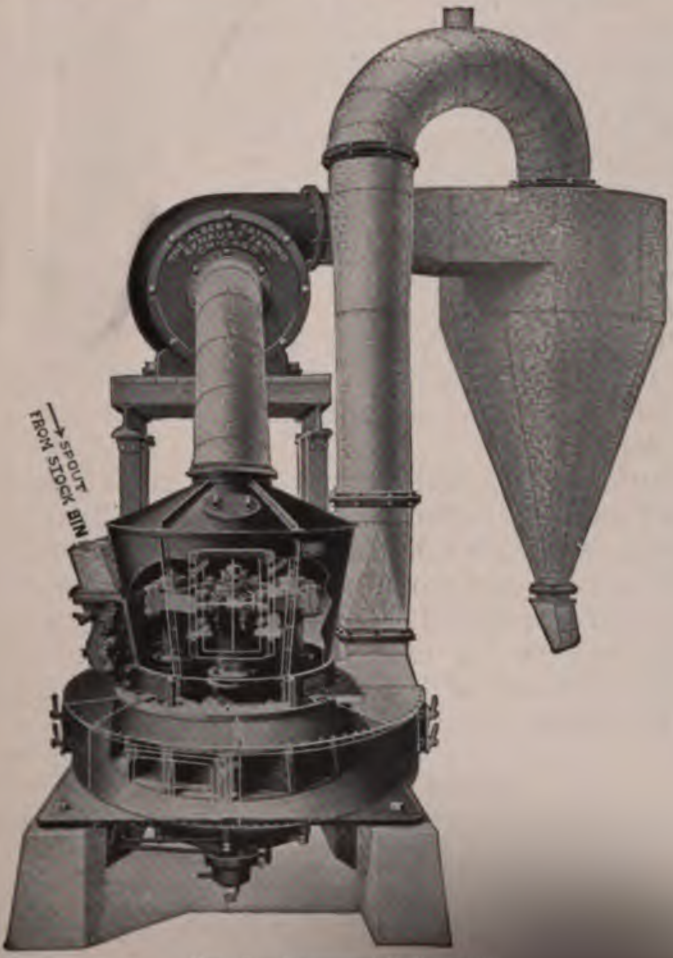


Fig. 7.—Raymond Roller Mill.

Centrifugal force throws the rollers outward against the steel ball ring. A plow is located ahead of each roller. This constantly throws a stream of coal between the face of the roller and the grinding ring.

In the mills with air separation, air enters the mill through a series of tangential openings around the pulverizing chamber directly under the grinding ring and rollers. That portion of the coal which is reduced to the required fineness by one passage of the roller is instantly carried up by the air current to the receiving receptacle. That which is not ground sufficiently fine by the first roller is carried between the succeeding roller and the grinding ring to receive a second treatment.

If the mill is kept properly filled with coal, each of the plows will throw a constant stream between the two grinding faces, preventing direct contact of the roller and the grinding ring.

In this mill the casting supporting the plows is attached to and rotates with the slow-speed upright shaft, and little power is required to raise the coal and throw it between the crushing surfaces of the roller and the grinding ring. The plows can be removed without taking the mill apart, by simply opening one of the doors. The construction is such that the faces of the rollers always remain parallel with the face of the grinding ring.

POINTS ON AIR SEPARATION

To obtain perfect separation and secure an impalpable powder, the air must be expanded and rarefied so that coarse particles will drop out of the current.

To obtain a large quantity of impalpable powder per hour by air separation, a large volume of air must be used in order to lift the material.

To use a large volume of air and yet obtain a current so light as to carry off only the impalpable powder, there must be ample room to expand and rarefy the air.

To secure perfect separation, the mechanism for expand-

VOLUMES AND WEIGHTS OF DRY AIR AT ATMOSPHERIC PRESSURE, 14.6963 POUNDS PER SQUARE INCH

$$\text{Weight in pounds per cubic foot} = \frac{.080728}{1 + .0020358(T - 32)} \qquad \text{Volume in cubic feet per pound} = \frac{1 + .0020358(T - 32)}{.080728}$$

Temp. Deg. F.	Volume as Compared with Volume at 32°.	Weight of 1 Cu.ft. of Air in Pounds.	Volume of 1 Lb. of Air in Cubic Feet.	Temp. Deg. F.	Volume as Compared with Volume at 32°.	Weight of 1 Cu.ft. of Air in Pounds.	Volume of 1 Lb. of Air in Cubic Feet.
0	.9349	.08635	11.581	700	2.3599	.03421	29.233
10	.9552	.08451	11.833	725	2.4108	.03348	29.863
20	.9756	.08275	12.085	750	2.4617	.03279	30.494
30	.9959	.08106	12.337	775	2.5126	.03213	31.124
32	1.0000	.08073	12.387	800	2.5635	.03149	31.755
40	1.0163	.07943	12.589	825	2.6144	.03088	32.385
50	1.0366	.07788	12.841	850	2.6653	.03029	33.016
60	1.0570	.07638	13.093	875	2.7162	.02972	33.646
70	1.0774	.07494	13.346	900	2.7671	.02917	34.277
80	1.0977	.07354	13.598	925	2.8180	.02864	34.907
90	1.1181	.07220	13.850	950	2.8689	.02814	35.538
100	1.1384	.07091	14.102	975	2.9198	.02765	36.168
110	1.1588	.06967	14.354	1000	2.9707	.02718	36.799
120	1.1791	.06847	14.606	1025	3.0216	.02672	37.429
130	1.1995	.06730	14.858	1050	2.0725	.02628	38.060
140	1.2199	.06618	15.111	1075	3.1234	.02585	38.690
150	1.2402	.06509	15.363	1100	3.1743	.02543	39.321
160	1.2606	.06404	15.615	1125	3.2252	.02503	39.952
170	1.2809	.06302	15.867	1150	3.2761	.02463	40.582
180	1.3013	.06204	16.119	1175	3.3270	.02426	41.212
190	1.3217	.06108	16.372	1200	3.3779	.02390	41.843
200	1.3420	.06015	16.624	1225	3.4288	.02354	42.473
210	1.3624	.05924	16.876	1250	3.4797	.02320	43.104
212	1.3664	.05908	16.926	1275	3.5306	.02286	43.734
220	1.3827	.05838	17.128	1300	3.5815	.02254	44.365
230	1.4031	.05754	17.381	1325	3.6323	.02222	44.994
240	1.4234	.05671	17.633	1350	3.6832	.02192	45.625
250	1.4438	.05591	17.885	1375	3.7341	.02162	46.255
260	1.4642	.05513	18.137	1400	3.7850	.02133	46.886
270	1.4845	.05438	18.389	1425	3.8359	.02104	47.517
280	1.5049	.05364	18.641	1450	3.8868	.02077	48.147
290	1.5252	.05293	18.893	1475	3.9377	.02051	48.777
300	1.5456	.05223	19.145	1500	3.9886	.02024	49.408
320	1.5863	.05089	19.649	1550	4.0904	.01974	50.669
340	1.6270	.04962	20.154	1600	4.1922	.01926	51.930
360	1.6677	.04841	20.659	1650	4.2940	.01880	53.191
380	1.7085	.04725	21.164	1700	4.3958	.01836	54.452
400	1.7492	.04615	21.668	1750	4.4976	.01795	55.713
420	1.7899	.04510	22.172	1800	4.5993	.01755	56.973
440	1.8306	.04410	22.676	1850	4.7011	.01717	58.234
460	1.8713	.04314	23.180	1900	4.8029	.01681	59.495
480	1.9120	.04222	23.685	2000	5.0065	.01612	62.017
500	1.9528	.04134	24.189	2100	5.2101	.01549	64.539
520	1.9935	.04050	24.694	2200	5.4137	.01491	67.061
540	2.0342	.03969	25.198	2300	5.6173	.01437	69.583
560	2.0749	.03891	25.702	2400	5.8208	.01387	72.104
580	2.1156	.03816	26.207	2500	6.0244	.01340	74.626
600	2.1563	.03744	26.711	2600	6.2280	.01296	77.148
620	2.1971	.03674	27.216	2700	6.4316	.01255	79.670
640	2.2378	.03607	27.720	2800	6.6352	.01217	82.192
660	2.2785	.03543	28.224	2900	6.8388	.01180	84.714
680	2.3192	.03481	28.729	3000	7.0424	.01146	87.236

ing and rarefying the air must be such that the coarse particles will drop out of the current and not carry the fine powder with them.

The apparatus must be so constructed that the coarse particles or tailings will drop by gravity into the contracted portion of the separator, where the blast is stronger, in order that they may pass out through the tailing spout or back into the pulverizer without carrying the fine material with them.

The nearer the condition within the air space of the apparatus can be made to approach a vacuum, the finer will be the separation.

COST OF LABOR AND MAINTENANCE FOR POWDERED COAL WITH RAYMOND PULVERIZERS

Total Cost per Ton, Cents.	Capacity in Tons per Hour.	Per Cent 100-mesh.	Per Cent 200-mesh.	Total Horse-power.	Horse-power per Ton.	Labor		Maintenance Cost, per Ton, Cents.
						Men at $2 per Day.	Cost per Ton, Cents.	
11.0	2	95	82	45	22.5	1	10.0	1.0
11.8	2	.....	95	60	30.0	1	10.0	1.8
7.6	3	95	82	60	20.0	1	6.6	1.0
8.4	3	.....	95	85	28.3	1	6.6	1.8
6.0	4	95	82	75	18.8	1	5.0	1.0
6.8	4	.....	95	120	30.0	1	5.0	1.8
5.0	5	95	82	85	17.0	1	4.0	1.0
5.8	5	......	95	145	29.0	1	4.0	1.8
4.3	6	95	82	120	20.0	1	3.3	1.0
5.1	6	.....	95	170	28.2	1	3.3	1.8
3.0	10	95	82	170	17.0	1	2.0	1.0
5.8	10	.....	95	255	25.5	2	4.0	1.8
2.6	25	95	82	425	17.0	2	1.6	1.0
4.2	25	.....	95	680	27.2	3	2.4	1.8

The cost in the above table does not include that of power, as this is variable with local conditions. The cost of maintenance when grinding 95 per cent 100-mesh is much less than when grinding 95 per cent 200-mesh. As a general rule, doubling the fineness of the mesh doubles the maintenance cost.

The Jeffrey Swing Hammer Pulverizer. In the past few years, the swing hammer pulverizer has proved itself to be an efficient machine for the pulverizing of coal and other materials.

The machine shown in Fig. 8 pulverizes coal by striking it while in suspension, as opposed to the rubbing and abrasion mills which roll and mash the coal between hard surfaces. The material to be reduced is fed in near the top of the machine, and in falling comes in contact with rapidly revolving hammers, which drive the coal against the breaker plates, from which it rebounds again into the paths of the hammers.

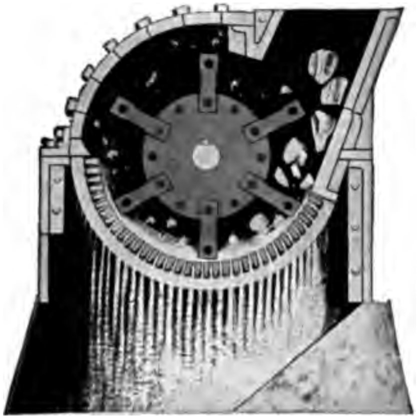


FIG. 8.—Jeffrey Swing-hammer Pulverizer.

Fineness is to a large extent determined by the intensity of the blow, and hence different degrees of reduction may be had by simply varying the speed of the machine. Different materials and different conditions of the same material as to temperature, moisture, etc., will result in corresponding differences in the degree of reduction, so that it is impossible to predict beforehand [illegible] to be expected from any particular material [illegible]

The supply of coal may be fed [illegible] directly from a large bin, some sort [illegible] device being desirable. The coal falls down on a sloping breaker plate where it is engaged by the rapidly moving hammers. The partially reduced material immediately passes over the cage of screen bars. Here all that is sufficiently fine will pass through, while the residue is carried around the machine for a second operation. The top breaker plate materially assists in reducing oversize coal.

The Aero Pulverizer. The Aero pulverizer, Fig. 9, consists of three interiorly communicating chambers (type " E " has four) of successively increasing diameters, in which revolve paddles on arms of correspondingly increasing lengths. The separate chambers are in fact separate pulverizers on a single shaft, each succeeding pulverizer having greater speed at its periphery and therefore greater power for fine grinding. An additional chamber contains a fan, the function of which is to draw the more finely pulverized coal successively from one chamber to the next, and to deliver it through a pipe connection to the furnace under the impetus of a forced draft. The separate pulverizers and fan are enclosed in one steel cylinder. An adjustable feed mechanism controls and varies the quantity of coal admitted and delivered by the machine.

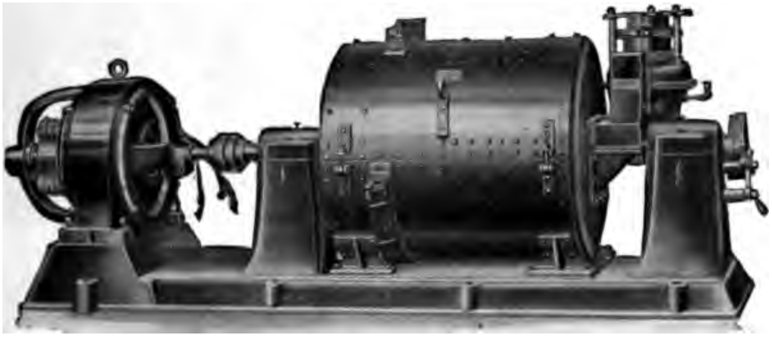


FIG. 9.—Aero Pulverizer.

The feed mechanism is exact and uniform in its operation and is easily adjusted to meet even minute variations in the fuel requirement. Two adjustable inlets in the feed mechanism admit the air required for the grinding. An auxiliary inlet between the last grinding chamber and the fan, controlled by a damper, admits such additional air as is required for combustion. The air dampers, with the feed control, give regulation of the flame within a wide range.

The discharge may be either right or left-hand as desired. The pulverizer is dust-proof and is arranged for easy repair to the parts susceptible to wear. The cost of such repair is small. The pulverizer may be located either in front of the furnace or at either side or above, or below.

The connection between the pulverizer and the furnace is usually a galvanized iron pipe. No additional feeding or mixing apparatus is necessary as the powdered coal and air are intimately mixed in the pulverizer. The furnace end of the discharge pipe is made of such size and shape as the furnace construction may require.

STANDARD SIZES OF AERO PULVERIZERS

Size	Weight, Pounds	Length, Inches	Floor Space, Inches	Normal Capacity, Pounds of Coal per Hour	R.p.m.	Normal Horse-power Consumption	Horse-power of Motor Recommended
A	[illegible]	[illegible]	[illegible]	[illegible]	2050	10	[illegible]
B	[illegible]	[illegible]	[illegible]	[illegible]	1750	11	[illegible]
C	[illegible]	[illegible]	[illegible]	[illegible]	1550	[illegible]	[illegible]
D	[illegible]	[illegible]	[illegible]	[illegible]	1450	40	[illegible]

Bonnot Pulverizer. The Bonnot pulverizer, Fig. 10, consists of a heavy one-piece main frame, which contains the grinding parts, consisting of grinding rolls and roll head or [redacted] frame is bored and lined with
ng a seat for the grinding ring.
rtically and is held in place
ing through to the
by
th

ring and are held in place and driven by the head or driver. The driver is recessed to receive the rolls and is so shaped as to converge the coal on the track in front of the rolls. It is a high-carbon steel casting with hard-wearing surfaces.

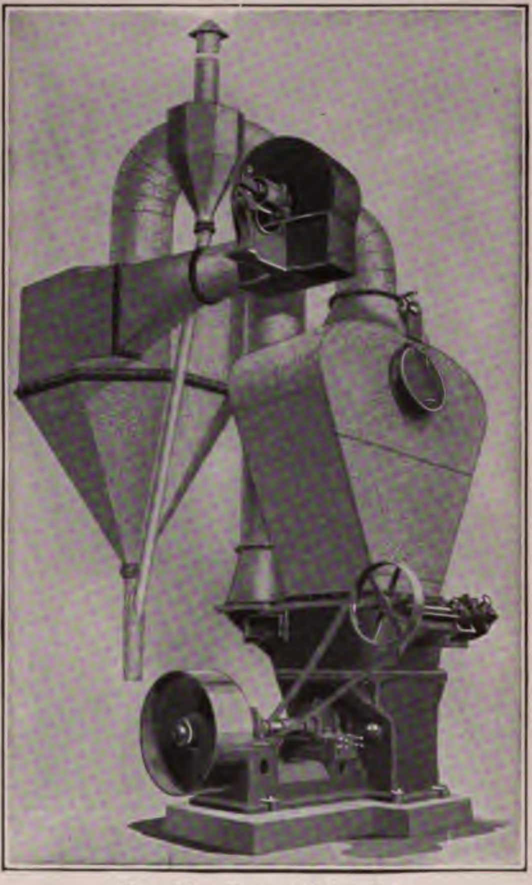


FIG. 10.—Bonnot Pulverizer.

There is a large cover plate on the side of the main frame, through which the driver, rolls and grinding ring may be removed without disturbing other parts.

This pulverizer is particularly adapted to use with a separator, owing to the fact that the grinding parts revolve in a vertical plane, and throw a constant stream of ground coal upward against the separator.

The base of the separator is attached to the top of the grinding chamber, and is made with the sides flaring or diverging so as to form a large air chamber into which the coal is thrown in a constant stream by the grinding parts. The air current entering at the bottom of the separator passes upward and carries away the fine material. Because of the increased area toward the top of the separator, the velocity of the air current is there reduced. This allows the coarser material to fall back into the grinding chamber, while the fine material is carried upward.

A feature of this separator is an interior flue on each side, by means of which a considerable range of fineness may be secured. These flues are hinged at the bottom and adjusted by a lever on the outside of the separator. To obtain a fine product, the flues are inclined outward to a position parallel with the walls of the separator; while for obtaining a coarse product, they are set in a vertical position. It is possible, without changing the speed of the fan, to obtain a range of fineness, from 98 per cent through a 200-mesh and practically all through 100-mesh, to a product of which 50 per cent will pass 100-mesh, and the balance range in size to 16-mesh or even coarser. The velocity of the air current and the position of the flues will determine the degree of fineness.

The air current carrying the impalpable material passes from the separator through a pipe to the collector, entering the latter on the side, in a horizontal direction.

Since the collector is polygonal in shape, the various sides or faces break up and change the direction of the air current, meanwhile reducing the velocity. This allows the material in suspension to drop to the discharge pipe at the bottom of the collector. At the top of the collector, a connection leads to a small auxiliary collector of similar shape, which is designed to remove any moderately fine material still remaining in suspension.

The Tube Mill. The Bonnot tube mill consists of a cylinder of steel plate, usually made from 4 to 5 ft. in diameter and in any length from 15 to 25 ft. The heads of the mill are lined with hard iron plates and the cylinder with either silex stone or hard iron as may be desired. The cylinder is supported at each end on large gudgeons, which are cast solid with the circular steel heads forming the ends of the cylinder. These heads are bolted to heavy cast rings running on large bearings. The mill is driven by means of a countershaft having a pinion engaging with a large spur gear attached to the cylinder.

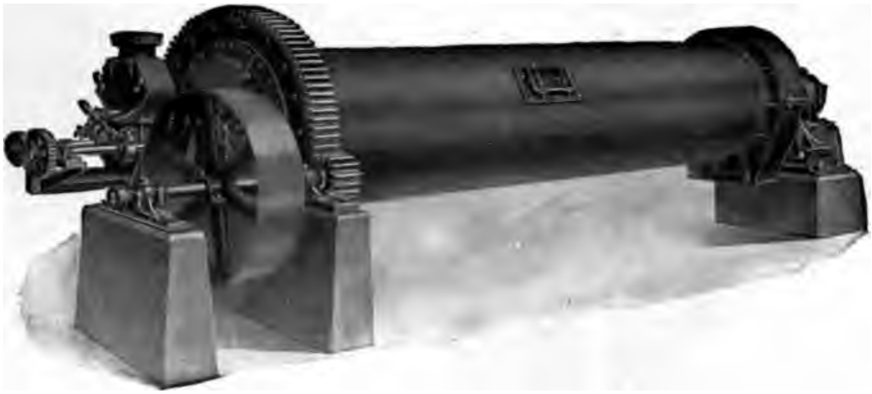


FIG. 11.—Bonnot Tube Mill.

The material is fed into the cylinder by means of a worm in the hollow gudgeon at one end of the mill. The feeder is an automatic regulating device and can be adjusted instantly to give any desired capacity up to 50 per cent above the normal capacity of the mill. It is supported by a heavy bracket bolted to the main bearing. It is driven direct, by means of gearing from the end of the gudgeon.

The material is discharged from the mill either through the hollow gudgeon at the discharge end, or through the end of the cylinder by means of slotted holes through the liners and discharge head. When the latter arrangement is used, a close-fitting cast-iron dust housing is provided, which is supported by brackets resting on the main bearing. The fineness of the product obtained is regulated by the amount of material fed into the mill.

This tube or pebble mill is economical with regard to wear owing to the fact that it is a slow-running machine and grinding is done by the rolling or impact of flint pebbles, with which the cylinder is filled about one-half full. Such materials as cement clinker and similarly hard, gritty substances are handled advantageously by the tube mill. The efficiency of the mill is not reduced by wear on the pebbles and lining, provided the normal charge of pebbles is maintained. Some tube mills use lengths of pipe or tubing, or steel-plate punchings, instead of loose pebbles. All grind very fine; so fine, in fact, as to be frequently expensive in power.

CAPACITIES OF TUBE MILLS

A 5 by 22 ft. mill with Silex lining, containing 6 tons of pebbles, fed with coal not exceeding ¼ in. size, ground 1½ to 2 tons per hour, 94 per cent to 100-mesh.

The same mill, with pebbles and 4-ft. tubes, ground 2¼ tons per hour, 95 per cent to 100-mesh.

A No. 18 Kominuter mill grinding 10 to 12 tons per hour sent all tailings which would pass over a ½ by $\frac{1}{16}$-in. screen to a Bonnot tube mill loaded with punchings. Two such mills, 5 by 9 ft., ground 4½ tons of the tailings per hour, 96 per cent to 100 mesh.

A 5 by 22 ft. Silex-lined mill loaded with 11 tons of slugs ground 3½ to 4 tons per hour, 96 per cent to 100 mesh. A precisely similar mill on a succeeding day produced this same fineness on 4½ to 5½ tons per hour.

CHAPTER IV

FEEDING AND BURNING POWDERED COAL

In a paper before the American Institute of Mining Engineers, 1913, Mr. H. R. Barnhurst lays down certain principles of which the following is an abstract: When coal is shoveled or fed in bulk, a certain degree of comminution or pulverization takes place in the fire as an incident of combustion. Coal does not burn in lumps, but its ash comes away pulverized. This gradual pulverization occurs in the fire at the expense of some of the heat units in the fuel. As this pulverization is accomplished slowly, it is necessary to supply a large grate area so that the collective surface exposed for disengagement of heat shall be sufficient for the purpose for which the fire is used.

To be classed as a fuel a material must be able to give out more heat than it receives. No fuel will burn until its particles are brought to this self-supporting condition by the heat absorbed from particles previously burned. Not only this, but the oxygen of the air must be heated likewise to a combining temperature. This involves heating the accompanying nitrogen. This heat must be passed from substance to substance in increments small in themselves but collectively as large as the occasion demands.

In the use of powdered coal the fuel is already prepared for the absorption and evolution of heat. In addition, it is aimed to prepare the air, by a practically similar subdivision, for joining in the process. The delivery of coal and air to the furnace must be controlled so that the proper amount of each will be secured.

The sequence of events in combustion is as follows: the volatile elements of the fuel are first disengaged. These highly combustible hydrocarbons combine with the oxygen of the air, burning to CO_2 and H_2O, and disengaging heat enough to bring up to an ignition temperature the fixed carbon components.

It is evident that comparatively large masses of fuel supplied with large volumes of air will, for reasons simply mechanical, fail in efficiency. This is more particularly the case when large contents of volatile matter are suddenly set free by contact with another mass of incandescent fuel and with heated surroundings. Under such conditions it is impossible to get the best results from any fuel. The sweeping-off of volumes of volatile gases by large volumes of insufficiently heated air produces smoke. This smoke represents but a small weight of carbon unburned, but may indicate a condition under which a large quantity of gases passes off uncombined. A heavy draft pressure accentuates this condition, and records are plentiful of the passage through fires of large excesses of oxygen which has failed of its duty from lack of heat preparatory to combination.

A pulverized fuel, the particles of which are each sursounded by a minute envelope of air, sufficient thoroughly to burn them, is an ideal fuel under ideal conditions. In projecting a cloud of such fuel into a highly heated chamber, each particle because of its opacity becomes an absorbent of heat, radiating not only from the chamber walls, but from each neighboring particle as it inflames. This inflammation progresses with rapidity almost inconceivable. Pulverized fuel injected with its air supply at a speed of several thousand feet per minute inflames right up against the delivery nozzle, the flame playing about its mouth. This is best accomplished by avoiding high pressure in projecting the fuel. The final combination of air and fuel occur
instant of projection into the furnace. Th
the fuel expands as soon as it is heated.
is of course due to the increase in temperat
the large volume assumed by the flame on
of entrance.

The powdered coal problem is one of

peculiar conditions. The burning of powdered coal differs from the burning of solid fuel in one essential particular. In the combustion of coal in commercial sizes lying on the grate, the air for combustion passes between the pieces of coal and the products of combustion pass off in the flue. Powdered coal does not burn under such conditions, as the particles are so fine that sufficient air for combustion could not reach the coal through crevices between the particles lying in a solid bed. To burn powdered coal successfully, it must be burned while in suspension in the air. In such a position each particle is surrounded by air which supports the combustion. The form of furnace used in making Portland cement is favorable for combustion in suspension, since it is very long and affords plenty of room.

Contact of the particles of coal dust with other bodies results in the lowering of temperature to such an extent as to make combustion impossible. There is a more or less complete loss of any fuel which falls down to the grate. The time for combustion is evidently increased as the size of the dust particle is increased; from which it follows that the finer the grinding, other things being equal, the quicker and more perfect will be the combustion.

In the early days of development of the process of powdered coal burning, ignorance of the necessity of fine grinding was the cause of many failures in burning the fuel. In the cement industry, special devices for regulating the supply of air for injecting the fuel are supplied, but no special controlling apparatus is supplied for the air which enters the kiln through the various openings around the hood. It would be difficult to control the admission of such air: but by increasing the fuel charge, it is possible to bring the air supply down to any relative proportion desired.

Patents taken out many years ago for the burning of powdered coal under boilers and in various arts show variations in the kinds of pulverizers and feeding devices, and also foreshadow the idea of delivering the powdered coal into the furnace by a jet of air or steam.

The perfect combustion of 1 lb. of carbon demands 2⅔ lb. of oxygen. This is contained in 11.6 lb. of air, or about 154 cu.ft.; should less than this quantity of air be supplied, a proportionate amount of fuel will be burned to CO, with a loss of two-thirds of its potential efficiency. A part of this loss may be regained by contact with heated oxygen; or the CO may pass on and burn in the chimney, doing no good. Carbon monoxide is necessarily formed in an atmosphere of gases deficient in oxygen, and its formation renders still more difficult the further establishment of active combustion.

The temperatures attainable with powdered coal are very high, so high that excess air is commonly admitted in proportions ranging between 50 and 100 per cent. This excess air dilutes the gases resulting from combustion and lowers the temperature.

The following table shows the temperatures attained in the perfect combustion of pure carbon with varying amounts of air:

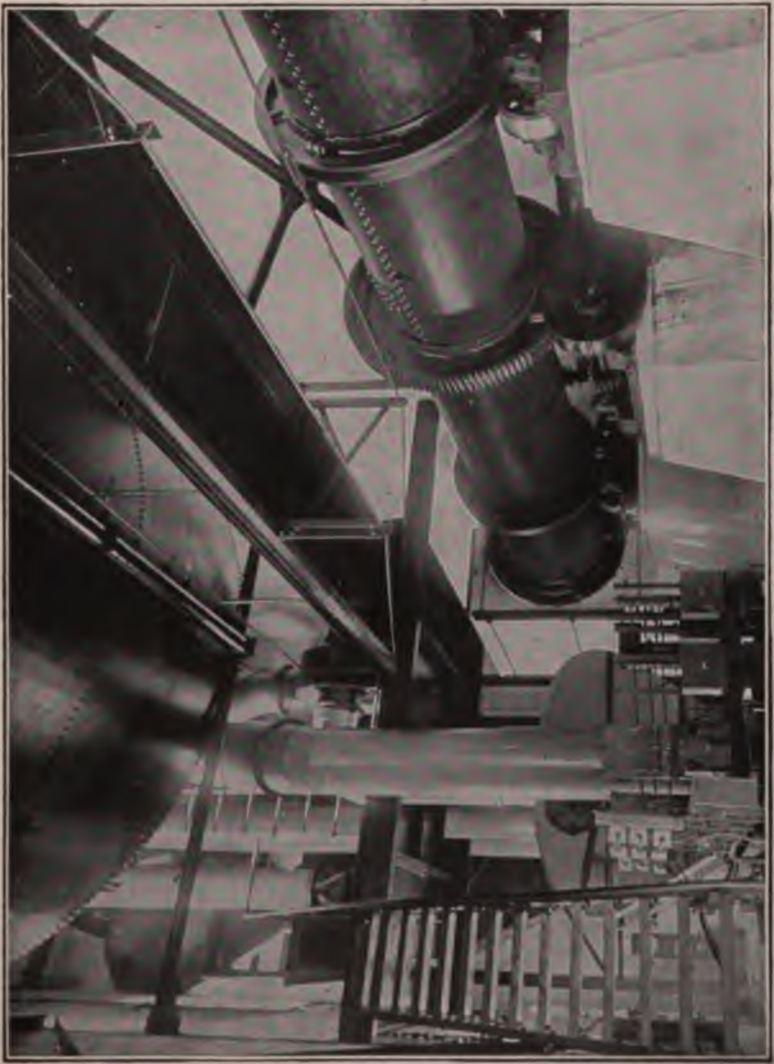
	Deg. F.
1 lb. carbon with 11.6 lb. air (normal)	3990
1 lb. carbon with 12.76 lb. air (10% excess)	3747
1 lb. carbon with 13.92 lb. air (20% excess)	3526
1 lb. carbon with 15.08 lb. air (30% excess)	3333
1 lb. carbon with 16.24 lb. air (40% excess)	3153
1 lb. carbon with 17.40 lb. air (50% excess)	3002
1 lb. carbon with 18.56 lb. air (60% excess)	2849
1 lb. carbon with 19.72 lb. air (70% excess)	2725
1 lb. carbon with 20.88 lb. air (80% excess)	2509
1 lb. carbon with 22.04 lb. air (90% excess)	2847
1 lb. carbon with 23.20 lb. air (100% excess)	2345

In practice, the furnace tender soon becomes educated to the point of judging whether a fire is hot enough by its color and by the length of the flame. The more perfect the conditions the shorter and whiter the flame.

Some fuels can be burned almost without care on the part of the operator; gas is one and oil another. There i no economy in such ways of operating, but the furnace undeniably hot. Mr. A. S. Mann, of the General Electric Company, remarked: "I recall an instance where an oil man wanted a really good fire and had no oil to waste. He watched the fire all the time and kept it right; if he eased off his oil a trifle he cut down his air too and did not forget to look at the chimney, top and bottom. Such work always pays, whatever the fuel may be.

"Powdered coal is not a fuel that can be left for half a day to itself while the fireman goes to grind his knife and pare an apple." Fires may run all day with no change in adjustment whatever, but somebody should always know that they are right; and the fire should be looked after every half hour or so. There is always slag and some fine ash forming; it is well to know where these are going. On the other hand a wrong adjustment of either coal or air soon makes itself apparent. Powdered coal burns best with a supply of 200 cu.ft. of air for each pound. It can burn, and burn clearly, with 160 ft. and even less, but the excess pays. When the supply exceeds 200 ft. efficiency begins to fall. There is a noticeable loss even at 208 ft. The eye cannot discriminate between a 200-ft. and a 208-ft. fire, but it can recognize a 250-ft. or even a 220-ft. blaze. There is a marked change in the appearance; and unless a "cutting" fire is really wanted, there is no excuse for such bad mixtures.

"This is not true of other fuels. Solid coal on a grate is not doing its best at 200 ft., and it takes a remarkably close observer to note the difference with a 240-ft. fire. With oil this is even more pronounced. It is the usual thing to find an oil fire with air greatly in excess, and the fact not known. The average operator will not even try to find out whether he is wrong, for in order to do so he must reduce his air little by little until things go wrong, and that takes time. Firemen are 'not paid to save fuel.' The powdered coal fire begins to spark and wheeze when it has too much air. 'In a typical powdered-coal feeding and burning installation, the coal is received in a bin over the feeders,



Pulverized Coal Plant.

where its weight is about 38 lb. per cubic foot when it is loose in the bin. Settling brings the weight down to about 45 lb. per cubic foot. Across the bottom of this bin, and within a pipe extending horizontally from it, is a double-flight worm or feed-screw. This double-flight screw resists the tendency of the light coal to flow of itself along the feed-screw. The screw extends over a flanged pipe-cross into which the fuel is delivered. The rear end of the screw is supported by a bearing in a flange on the side of the bin, the shaft projecting to receive a driving pulley or chain sprocket. The delivery end of the screw shaft is supported by a bearing in the cover of the horizontal opening of the flanged pipe-cross. The top opening of the cross is uncovered to permit air to draw down with the falling fuel. This fuel descends a vertical pipe attached to the lower opening of the cross, the pipe being long enough to be within the funnel or injection pipe. At the bottom of the funnel is a diagonal plate upon which the fuel falls. The plate is tight against the air pipe on the up-stream end, and is flared open, on the side towards the furnace (down the current). It covers about one-fourth the diameter of the pipe, thus forming at this point a 'vena contracta,' and producing a suction in the funnel. Consequently, supplementary air is drawn through with the fuel. The fuel spraying upon this plate mixes very thoroughly with the air from the fan, the eddy currents assisting materially in dispersal of the fuel through the main column of air.

"The admission funnel should be far enough from the furnace to permit this mixture to be thorough. Pressures carried abnormally high may defeat this, and they also tend to project the fuel too far into the furnace before flushing. As soon as the fuel cloud begins to absorb the heat of the chamber into which it passes, a rapid expansion of the air takes place, separating the particles of fuel in suspension. The amount of expansion is determined by the ratio of the absolute temperatures, in the furnace and of the initial air. It is a matter of discussion whether the best results are obtained by a delivery of all the air found necessary for combustion through the feed pipe, or to use a smaller quantity of air in the feed pipe and provide a further supply from other openings. Good practice would seem to point to absolute control of the air by the fan, and control of the fuel by a varied speed of the feed-screw. The furnace should have a good natural draft to a chimney, controlled by a damper."

FURNACES

The designing and building of furnaces is an undertaking that calls for engineering skill. Speeds, volumes and currents must all be considered; sizes and areas influence heat generation and distribution; the position of the egress ports, if their number or size is great, may defeat the purpose of the furnace. It will not do to build a furnace in a haphazard way, apply a burner somewhere and, if it does not work, feed in enough fuel to make it work. Perhaps there is no fuel so sensitive to correct use as powdered coal.

While coal ignites freely, in a hot chamber, this ignition necessitates the absorption of heat from some source, and if coal rapidly projected by air does not develop its heat near the point of ignition, other means must be devised to maintain the heat necessary for ignition where ignition is needed, i.e., at the first entrance of the coal into the furnace. Giving the fuel too great velocity upon entrance is not good practice.

Some singular errors and misconceptions have attended the practice of many users of powdered coal. More particularly is reference intended to the use of large fans to supply the air necessary for the projection of the fuel, where the air nozzle is reduced from 16 or 18 in. in diameter to 4 or 5 in. at the jet with the expectation that all of the air in the 16 or 18-in. pipe will be hurried [illegible] the 4 or 5-in. nozzle.

The first essential of a po [illegible] e combustion chamber where four times the volume of the flame produced by an ordinary grate fire. This entire combustion space must be free from any metallic cooling surfaces. There is little possibility of such a cooling surface in most metallurgical furnaces, but this is the probable reason why powdered coal has had thus far only limited application under steam boilers. Contact with a cooling surface stifles the flame and stops combustion. The reverberatory type of furnace is well suited to the use of powdered coal. It has a large combustion space, which in the case of powdered coal extends out over the hearth. In all cases, the fuel must be projected into a chamber sufficiently hot to cause instant deflagration. The furnace must be properly proportioned, properly equipped and in good condition.

BURNERS

There have been filed in the United States Patent Office almost as many patents on powdered fuel burners as on non-refillable bottles. Almost any engineer can design a successful burner after knowing the requirements. "Any mechanism which will give a uniform mixture of coal and air with both under control can be used as a burner for powdered coal."

Burners are usually made up of a screw conveyer of variable speed which drops the coal into a blast of air. One thing to be guarded against is the possibility of flushing. Powdered coal seeks its own level like water. It will sometimes run along a screw conveyer so as to get ahead of the screw. For this reason the screw is usually made very long, so as to introduce enough friction to keep back the flush of coal.

There is one very successful burner in which no mechanism whatever is used, everything depending upon the blowing of air through a pocket of powdered coal. The air picks up enough of the powder in its passage through to provide for combustion. Possibly this apparatus would have a closely limited capacity.

Some of the failures that have been experienced in burning powdered coal have been due to an incorrect method of introduction of air into the furnace, either by induced draft or by a blast separate from that which supplies the coal. Air and fuel must be mixed thoroughly before entering. It is possible to add a little more air after a mixture has been made, but good combustion should be first insured by a good mixture of fuel and air at entrance.

The burner must be designed so as to be free from pockets or storage spaces, and must be out of the influence of the heat of the furnace. Heat will cause coke to form and interrupt the operation.

One of the first patents granted in connection with powdered coal was that to Messrs. Whelpley and Storer in 1866. It covered the simple operation of feeding powdered coal so as to cause it to come into contact with the supply of combustion air. The pulverized coal was to be employed merely in order to assist solid coal fires already burning in the furnace. The idea was that the fuel entering with the column of air would meet, near the point of entrance, the flames of the furnace fires. Thus as the powdered coal entered the working chamber, it was instantly and thoroughly consumed. It was not intended to dispense with the usual fires maintained in the fire box of the furnace, but merely to augment them and to economize in fuel.

In 1870, the same inventors were granted a patent covering a device for introducing and regulating the supply of powdered coal and air into furnaces and fire boxes, through a large number of openings (Figs. 12 to 13).

In 1871, Mr. T. R. Crampton was granted a patent for an improvement in apparatus for feeding powdered coal to furnaces, which consisted of six, eight or more or less b
according to the size of the furnace. Stream
with powdered coal were injected into the
bustion chamber (which had a plain soli
fire bars or divisions of any kind) thr
each other and on the same plane, so th

mingled as they expanded on leaving their respective pipes or openings. This assured uniformity of combustion superior to that effected with either a single pipe or with branches from a single pipe opening into the combustion chamber at places too remote from each other to permit sufficient commingling of the fuel and air.

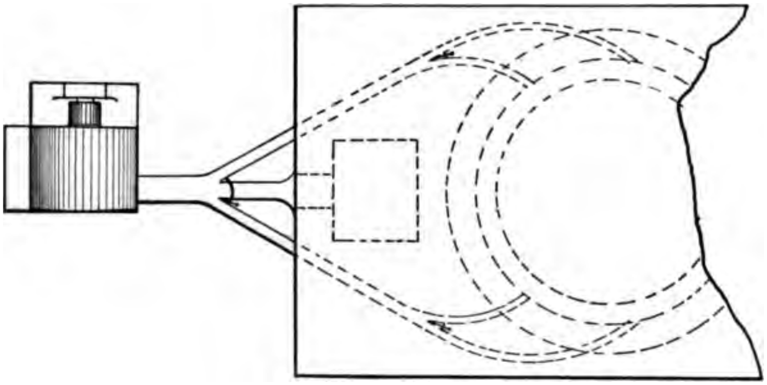


Fig. 12.—Whelpley & Storer Apparatus.

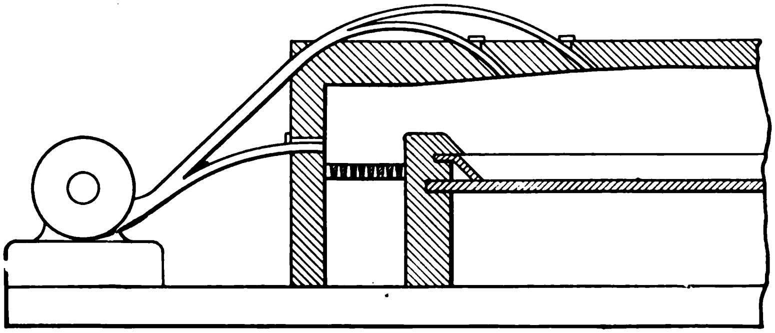


Fig. 13.—Whelpley & Storer Apparatus.

In order still further to promote combustion, the bridge wall was constructed with a suitable slope towards the openings, so that the commingled streams impinging on it at an angle spread in all directions. This led to a further commingling; and a combination of air and fuel homogeneous in its character was deflected over the bridge wall ready to do its work in the furnace.

Instead of relying upon the combination of air and fuel escaping from a single pipe as sufficiently perfect to secure continuous and uniform combustion, the fuel and air were thus subjected to, first, the action of similar streams from adjacent pipes; and, second, impingement upon the bridge wall, or even upon the bottom of the combustion chamber. The powdered coal, ground to the required fineness, was placed in rectangular reservoir, located above the plane of the pipes. In this reservoir there were rotating stirrers which urged the fuel through a gate at one end of the reservoir, and upon a roller, a part of whose periphery formed the bottom of a box attached to the reservoir which supported the fuel issuing from the gate.

Above the roller, just described, was another and smaller one, a part of whose periphery was within the box; the two rollers by proper gearing being made to move at about the same surface speed.

The rollers were adjustable as to speed, and received between their faces the powdered coal passing through the gate of the reservoir. They delivered it in a thin sheet of grains of uniform size into a trough, from which descended as many receiving tubes as there were conducting tubes leading to the furnace.

The upper openings of the receiving tubes in the trough were rectangular, and so arranged side by side as to divide equally the sheet of grains falling into them into as many portions as there were conducting tubes.

The bottoms of the receiving tubes were circular, and they were united each to its separate conducting tube, slightly on the furnace side of the open end of the latter.

Having thus secured to each conducting tube an equal supply of fuel, the next thing to be done was to combine or mix this fuel with air, and to force the combination, then called "carbonized air," into the combustion chamber. This was effected by a fan or similar contrivance. The blast of air was forced into a cylinder in the same plane with the conducting tubes, opposite to the open ends of which were an equal number of air nozzles.

These nozzles were smaller in diameter than the open ends of their respective tubes, and at a short distance therefrom, so that there was space into which the external air might enter into the conducting tubes along with that which was forced into them from the air nozzles (Figs. 14 and 15).

In 1871 a patent was granted to Mr. J. Y. Smith of Pittsburgh, Pa., on a device shown in Figs. 16 to 18, which the inventor describes as follows:

" An apparatus for feeding powdered coal into a furnace, combining in its construction the following elements, viz., an induction and an exhaust pipe, an intermediate wheel arranged to be revolved by the action of a current of steam, air or gas passing through said pipe, and a shoe or other feeding mechanism regulating the discharge of the powdered coal connected with said wheel."

In combination with a pipe or series of pipes for passing a current of steam or gas into the furnace or combustion chamber, there is employed a hopper or pipe for delivering into such current, the powdered coal; and an opening or series of openings for introducing air mingled with the steam or gas and powdered coal into the furnace or combustion chamber.

In 1876 Mr. Wm. West of Golden City, Col., was granted a patent for a powdered coal burner which consisted of a small screw conveyer for feeding the coal dust from a bin to one or more tubes; from which it dropped through a funnel-shaped pipe into a blast pipe. From this, the air picked it up and carried it into the furnace. The screw had a cone pulley or other means for regulating the speed of the conveyer (Fig. 19 to 20).

In 1880 Mr. West together with Mr. John G. McAuley improved the design of this powdered coal feeder and were granted a patent on their improvement. It consisted of constructing the feeder with a vertical conduit, through

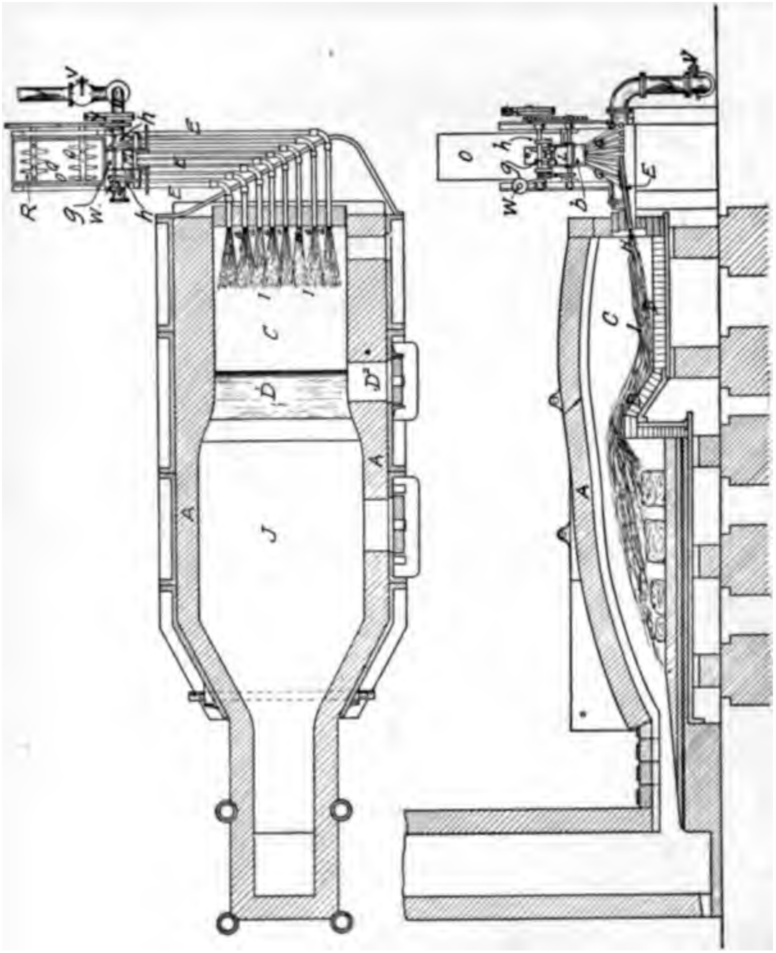


Fig. 15.—Crampton Apparatus.

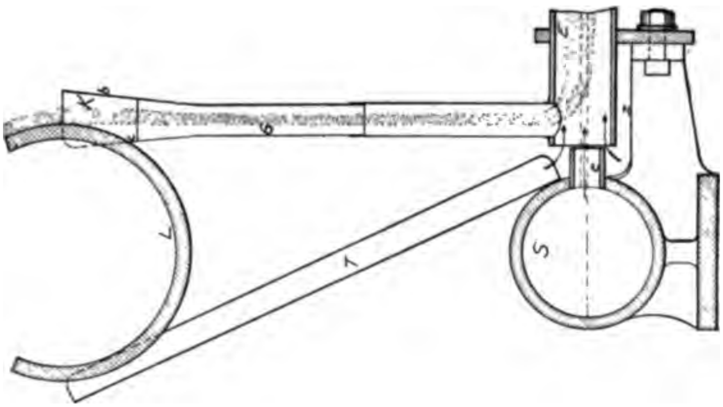


Fig. 14.—Crampton Aparatus.

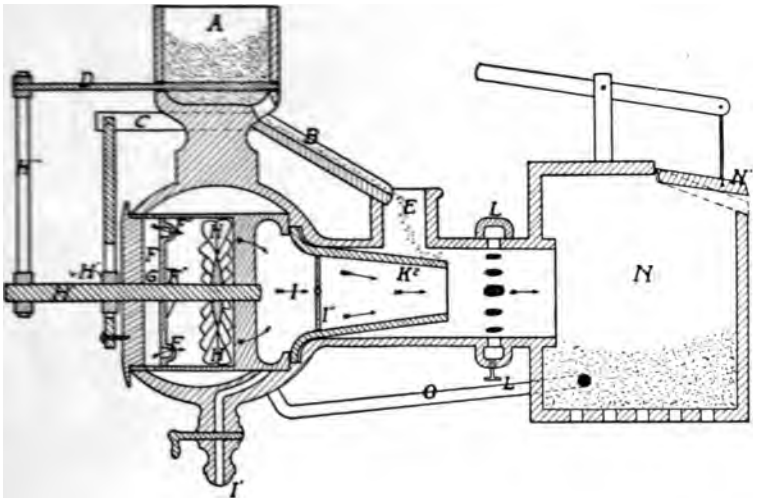


FIG. 16.—Smith Burner and Feeder.

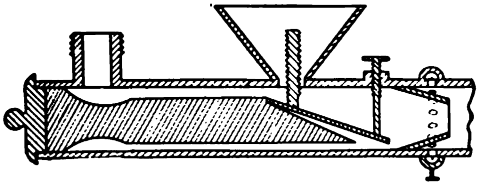


FIG. 17.—Smith Burner and Feeder.

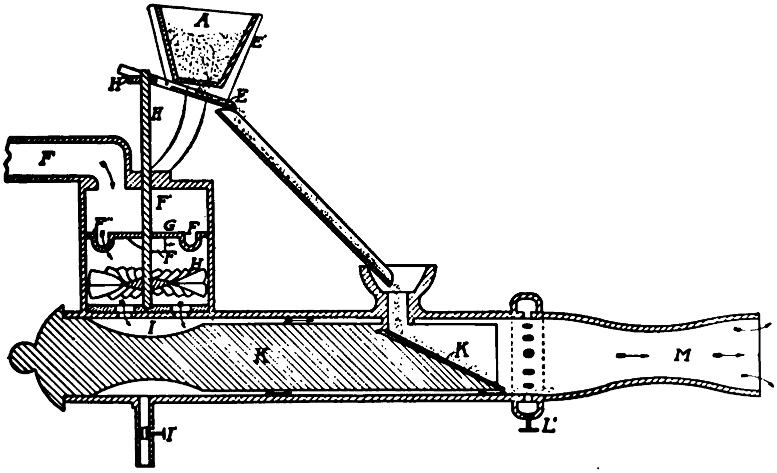


FIG. 18.—Smith Burner and Feeder.

which the powdered coal dropped, communicating with a horizontal pipe which was made of greater inside diameter

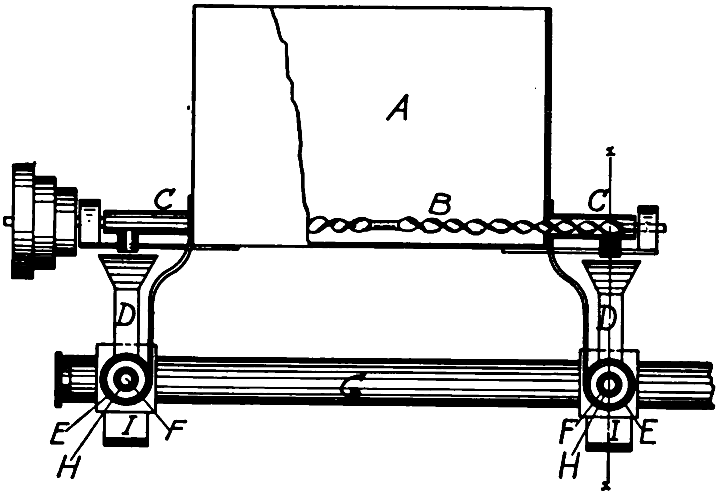


Fig. 19.—West Feeder.

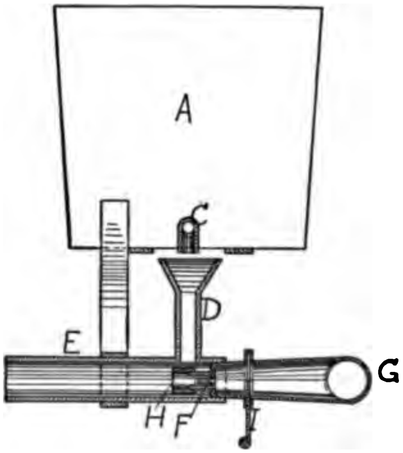


Fig. 20.—West Feeder.

just back of the point of entrance of the coal than it was farther back. An inclined shelf, at the bottom of the vertical fuel conduit, prevented the blast of air from strikin upward and made for a better mixing of the particles of coal dust and air.

The Edison patents on feeding and burning equipment are described in Chapter V. Other apparatus of this sort will be found discussed in Chapters VIII and IX.

Pneumatic Feeding System. In most plants using powdered coal the above-described screw conveyer system is employed. About a year ago the author visited a number of works using powdered coal. Among them were several that are using the *air distributing* (Holbeck) system; and the contrast between the two systems was most marked.

The air distributing system is briefly described as follows: Air is the agent used for conveying the coal dust to the furnaces. The coal is first pulverized in the usual manner and delivered to a storage bin located in the coal building. This bin is the only one used for storing powdered coal in the entire plant. It is made of sufficient capacity to serve the furnaces for ten hours.

The powdered coal is taken from this bin by a standard double-flight screw conveyer, driven by a variable speed motor: and is then fed into the suction side of a high-pressure blower. From this it is blown into the distributing main and carried to the furnaces through branch pipes. The coal which is not used at the furnaces is returned through a return line to a collector located on top of the powdered coal bin, where it is extracted from the air and falls into the storage bin to be fed over again. The air from the return line, after the coal is extracted, is returned to the suction side of the distributing blower.

Interposed in the distributing main is a special flow indicator and controller; intended, first, to indicate the rate of flow of air through the system and second, to control the feed of powdered coal into the system so as to have a uniform mixture of coal dust and air to the burners, regardless of the number of furnaces in operation.

The return line permits a velocity of air in the distributing main sufficiently high to keep the powdered coal in suspension of the air and in circulation in the system, even with no furnaces in operation.

When the valves in the branches at the furnaces are opened so as to permit a flow of coal dust to the burners, there is an increase in the flow of air through the flow indicator. This increased flow is instantly indicated on the indicator dial as shown in Fig. 21. At the same time a small pilot motor is started, and by means of proper gearing the arm of a special field rheostat is moved in proportion to the increase in the flow of air through the distributing mains. This rheostat controls the variable speed motor that drives the feed screw, thus speeding up this motor and feeding more coal dust to meet the demand. In case a valve of the furnace should be partly closed, thus causing a decrease in the flow of air through the system, the pilot motor is automatically reversed, the rheostat arm is moved in the opposite direction, and the motor driving the feed-screw is slowed down so that the mixture of coal dust and air is automatically kept uniform.

With this system, the powdered coal can be conveyed to any reasonable distance. The author has seen a plant where the first furnace was 400 ft. from the pulverizing plant, and another where the last furnace on the line was 1500 ft. from the milling plant. If the velocity of flow is reduced, due to friction in the main, a second or even a third and fourth distributing blower or booster can be placed in the line and thus the circulation can be kept up for an indefinite distance.

The advantage of handling the coal dust in this way over the old system of using screw conveyors, are:

1. When it is taken into consideration that the air used for conveying the coal dust is also used to take the plac
the secondary air for combustion, that would
furnished by some other means, the actual
of power for furnishing coal dust to the furnac

2. The wear and high cost of repairs incide
method of using screw conveyers is eliminat

d that a 9-in. screw conveyer costs about $4.50 per l foot and the power cost to turn it will average at least

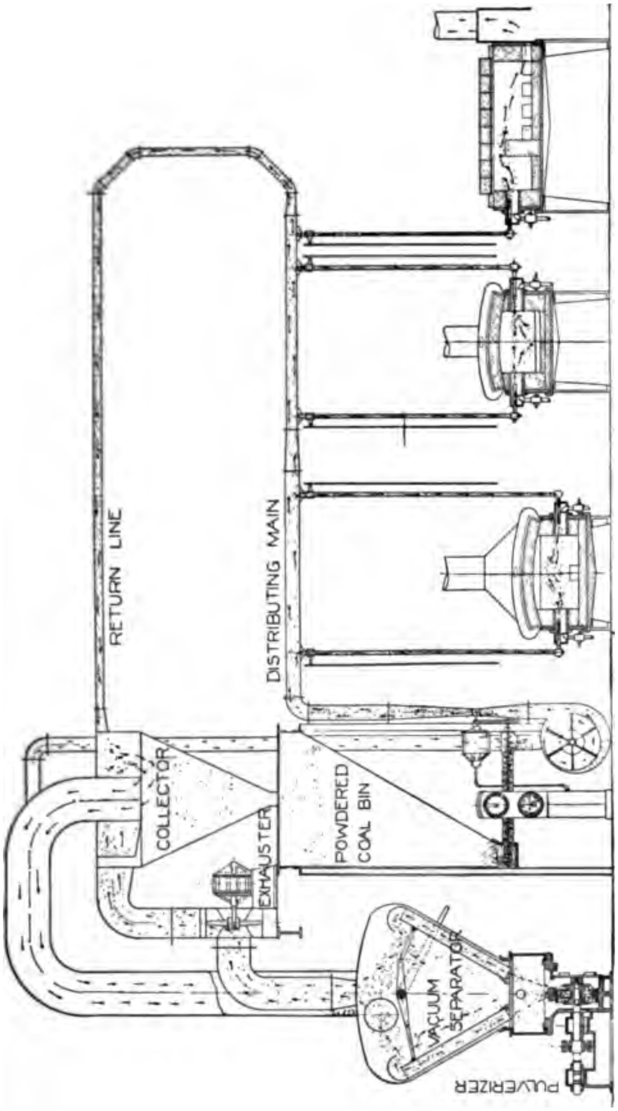


FIG. 21.—Holbeck System, Showing Indicator Dials.

0 per day for every run of 250 ft. Screw conveyers apt to clog up and stop feeding, necessitating work to te the stoppage and then to make repairs.

3. Air distribution entirely eliminates the storage bin at each individual furnace, which takes up a great deal of space that can be used for other purposes. It also eliminates the "hanging-up" of coal dust at the furnaces, which may cause avalanching and flushing past the controllers, leading the furnaces to puff or smothering the fire. This difficulty from powdered coal (caking at the bins) seems to be quite general. The writer has seen the coal dust bins suspended by springs in shops where it was endeavored to stop the caking of the coal resulting from the jarring of forge hammers.

4. Within a few minutes after the furnaces are shut off, all of the coal dust in the distributing system is returned to the pulverized coal plant, thus leaving no coal dust in storage in the works or at the furnaces.

With this system of distribution, there is no large combustion chamber built, nor is the existing furnace changed to any extent. The oil or gas supply is cut off and one or two small branches of pipe are brought down to the furnace with a valve near the main, fixed so that it can be operated from the floor.

The distributing main consists of spiral riveted pipe running overhead and feeding the furnaces. If there are ten or twelve furnaces, and it is desired to shut down one or more of them, the valves at the branches are closed and the automatic controller does the rest.

For getting rid of ash and smoke, the front side walls of the furnaces are built out and a sheet steel hood is placed directly across the front of each furnace, the bottom of the hood resting just above the work opening; each hood is tapered into a small pipe and connected to an exhaust main. At one end of the shop an exhauster is placed to which this exhaust main is connected and the content
discharged into a separator placed outside of the
Underneath the separator is a storage bin, from
ash can be removed.

CHAPTER V

POWDERED COAL IN THE CEMENT INDUSTRY

Among the various applications of powdered coal, the first was in the manufacture of cement.

About forty-three years ago, Mr. William Sweet of Dilworth, Porter & Company, was using powdered coal, employing a screw and fan to inject the coal into the furnaces. The coal was simply crushed as fine as it could be between ordinary rolls and this lack of the fineness required for burning probably accounted for the failure of the project.

For the past thirty years there have been suggested many schemes for burning powdered coal in cement plants, under boilers and in heating furnaces. A large number of burners and processes have been introduced with varying degrees of success.

During the early years of the cement industry in this country, *oil* was employed as a fuel by spraying it into the lower end of the furnace with a jet of compressed air or steam. The use of oil was successful, but due to the increasing cost after 1895, very expensive. From 1897 to 1900 the increase in price was so great as to make the use of oil almost impracticable commercially. This fact has been the principal incentive for developing the use of powdered coal.

In 1894 a series of experiments on the use of powdered coal was begun by the Atlas Portland Cement Company. These were in immediate charge of Messrs. Hurry and Seaman, Chief Engineer and Superintendent respectively. They led to many discoveries, the invention of various devices and finally to the commercial development of the art. Hurry and Seaman are entitled to the credit of having been the first successful users of powdered coal in the cement industry. This use was begun in 1895 by the Atlas Company and has never been discontinued. Other engineers working along independent lines attained success a few years later. Possibly they received some assistance from information disseminated throughout the industry relating to the results obtained by Hurry and Seaman. At the particular date referred to, every mill in the industry jealously guarded information regarding details of manufacture as valuable trade secrets. Consequently, little or no direct information as to details of processes or machinery employed was common in the different mills. The information which leaked out was generally inaccurate and inferences were based on speculation or rumors. The success of the process of burning powdered coal in the Atlas plant was not generally realized until about 1900, when the process was put in operation in various other plants by independent investigators.

Portland cement is manufactured from a mixture of materials containing lime and silica, which are brought together in definite proportions and caused to unite in chemical combination. The raw material is principally carbonate of lime, or limestone in some form, with clay or shale. The materials are pulverized raw and mixed, either in the form of a dry powder or in a wet condition. They are then delivered to the kiln, where they are subjected to an extremely high temperature, at which the required chemical combinations take place. In the early days of the art, fixed kilns were employed, but at the present time the rotary kiln is almost universally used.

According to Prof. R. C. Carpenter (Trans. A.S.M.E., Vol. 36), the rotary kiln in its essential features was patented by Siemens in 1869, and in combination with a gas burner and other appliances, by Ransome in 1885. It was not found successful for cement burning in England, but was improved and developed in the United States by the Atlas Company about 1890, and by other American companies, to such a degree that it displaced practically every other method of burning Portland cement.

"The modern rotary cement kiln consists of a slightly inclined steel cylinder mounted on steel rollers and arranged so that it can be revolved. The upper end is connected with a stack or chimney which permits of the escape of discharge gases. The raw cement material, in the form of dust or 'slurry,' enters the upper end of the kiln. At the lower end of the cylinder is a stationary hood which affords a discharge opening for the burned material and which also acts as a support for the fuel-supplying devices. The rotary cylinders are of various dimensions. The tendency has been continually to increase the size of cylinder. Thus, for instance, in 1890 the rotary kilns were in some instances 4 ft. in external diameter and 40 ft. in length. From 1895 to 1902 kiln dimensions were quite generally 6 ft. in diameter and 60 ft. long. At the present time kilns 10 ft. in diameter and 150 to 200 ft. long are common. The Atlas plant at Hudson is equipped with kilns 12 ft. in diameter and 275 ft. long. In most of the late installations the kilns are true cylinders having the same diameter at each end; but in many plants kilns are to be found with the diameter at the top about 1 ft. less than that at the bottom, the two parts being connected by a tapered section forming the frustum of a cone.

"The rotary kiln is lined throughout with a fire-brick lining, except in rare cases where a very wet slurry is employed, in which case the lining for a short distance from the upper end is omitted. The temperatures in the combustion chamber required for burning cement clinker are from 2800 to 3000° F. To withstand these high temperatures a lining having high refractory qualities must be employed. It must also have the quality of withstanding decomposition by the chemical action taking place in the kiln. The problem of kiln linings has been a serious one. The lower part especially has to be repaired frequently unless conditions are unusually favorable."

The kiln is so operated as to keep the lining coated with the cement mixture for the purpose of protection.

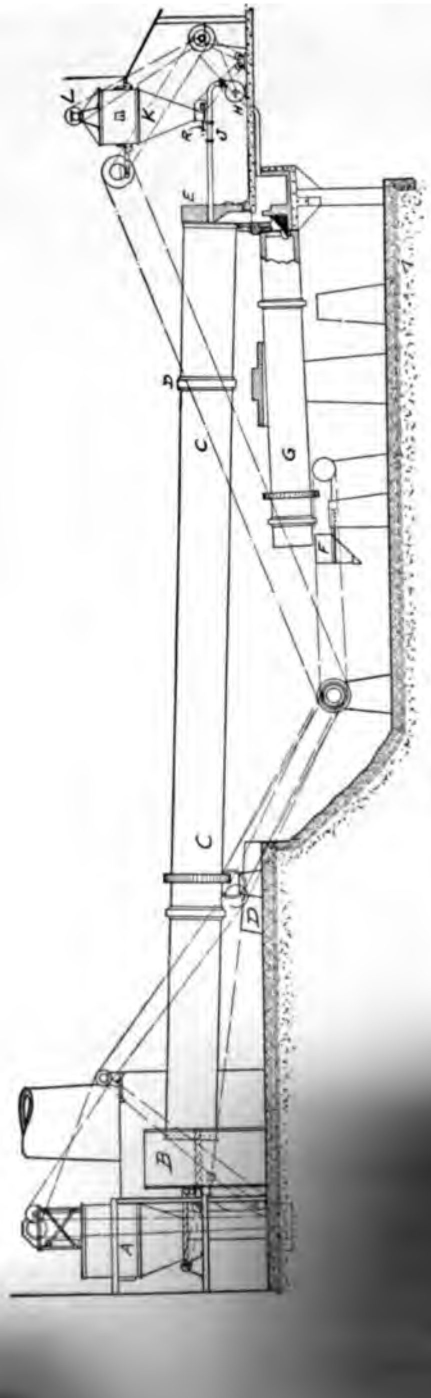


FIG. 22.—Rotary Cement Kiln.

Fig. 22 shows the general features and arrangement of the various operating parts of a typical rotary cement kiln. In this illustration the kiln is shown at *C*, the flue for discharge gases at *B*, the supporting rolls at *D–D*, the stationary hood at the lower end at *E*, the rotary clinker cooler at *G*, the clinker pit at *F*, the blower for supplying compressed air at *H*, the coal bin at *K*, the feeding injector for coal dust at *J*, the conveyer for delivering coal to the fuel tank at *L*, and the dust bin for raw material at *A*. The hood, *E*, is usually mounted on *rolls* so as to be easily moved away when repairing the kiln. It is customary to supply a separate stack for each kiln, although in some cases one stack received the discharge from two kilns. In a large installation it is customary to supply the air for several burners from one blower. In the installation shown, the blower draws in air which has first been warmed by passing through a rotary clinker cooler.

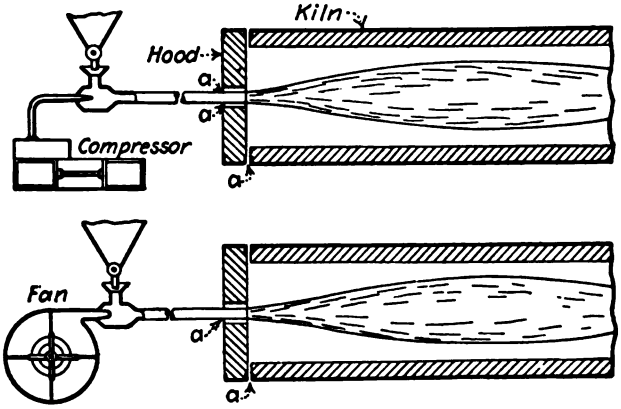


FIG. 23.—Injector for Cement Kiln.

Fig. 23 gives an idea of the character of the combustion which takes place in the burning of powdered coal in a cement kiln. The powdered coal is delivered to the kiln by a jet of air which impinges on the fuel dust with force enough to discharge the dust into the kiln. The compressed

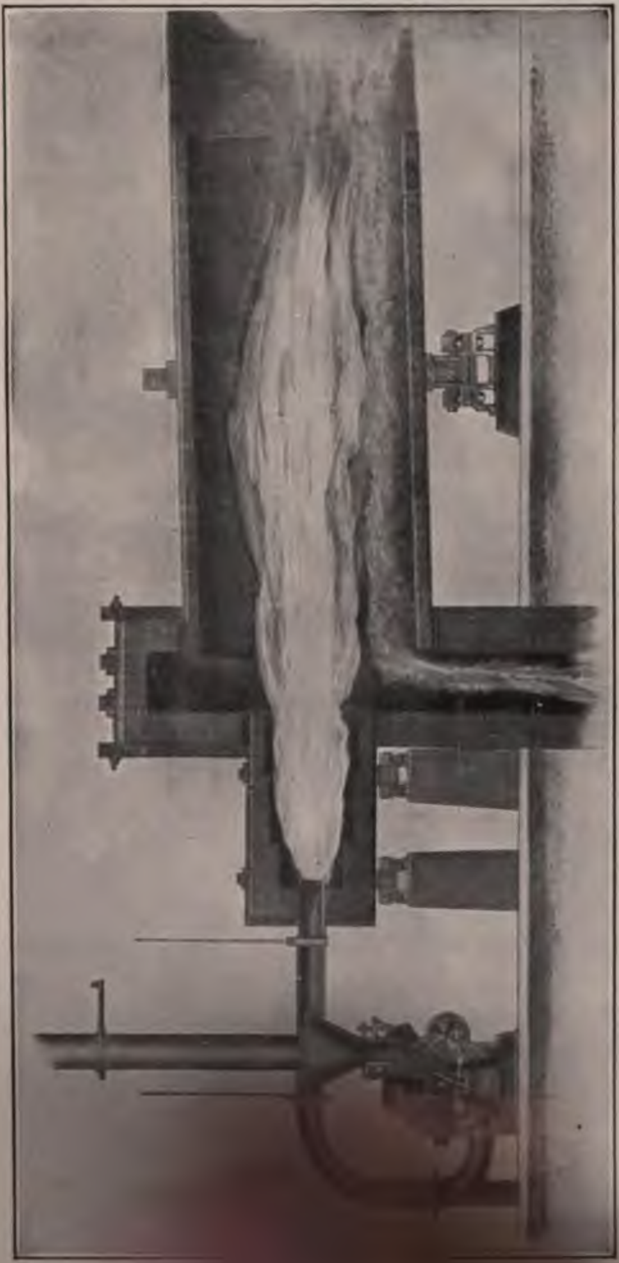


Fig. 24.—Elongated Flame in Cement Kiln.

air may be obtained from a fan or a compressor, as may be convenient; the illustration shows both schemes.

The injector varies greatly in different constructions, but in all cases it performs the function of injecting the coal dust into the kiln by a jet of air. It always consumes less than the amount needed for combustion. The additional air needed for combustion enters the kiln principally through openings in the hood and through the discharge duct for clinker. Such openings are shown in Fig. 23 by arrows at points marked *a*. The amount of air supplied by the compressors or fans should be sufficient merely to carry the dust into the kiln without producing a combustible or explosive mixture. The fuel dust enters the combustion chamber of the kiln in the form of a black cloud and burns like an elongated torch, as indicated in Fig. 24. The length of the flame in actual kiln constructions is generally from 25 to 40 ft., although this is affected by local conditions. The diameter of the flame in some places may be very nearly equal to that of the combustion chamber. Under the best conditions of burning the flame does not perceptibly impinge against the side walls of the kiln, and the heat utilized is practically all given off by radiation.

EDISON SYSTEM

In 1904, Mr. Thomas A. Edison designed and patented a method of burning Portland cement clinker by the use of powdered coal, which is described as follows:

The invention consists in a method whereby a greater amount of fuel may be consumed in kiln cylinders without raising the temperature to which they are now usually subjected. Thus the desired quality of material is secured, while the output thereof is largely increased.

" The rotary cylinder burners heretofore in common use for burning Portland cement materials consist of a cylinder about 60 ft. in length lined with fire brick and having [illegible] inside diameter of from 4 to 5 ft., the [illegible] a slight angle and the powdered coal

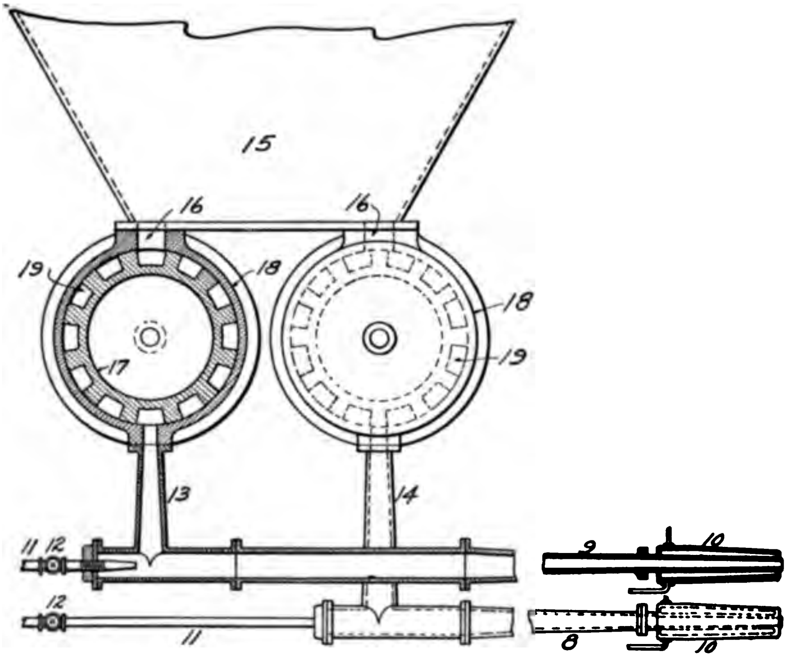


FIG. 25.—Edison System.

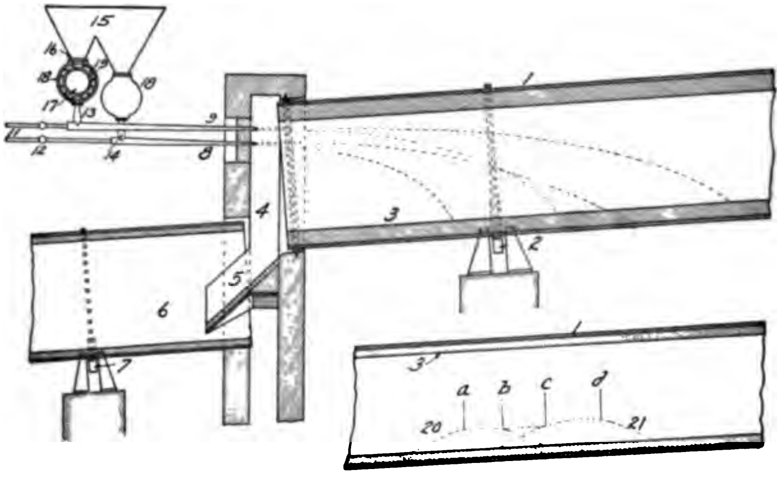


FIG. 26.—Edison System.

end thereof. The rotation of the cylinder, by reason of its inclination, slowly advances the material toward and out of the lower end. The speed of progression of the material lengthwise through the cylinder depends upon the speed of rotation and the inclination of the cylinder. The exit or lower end of the cylinder opens into a closed chamber provided with an orifice at the bottom through which the burned material may make its exit.

"With such cylindrical kilns as have heretofore been used, there is inserted in this chamber, in an axial line with the bore of the cylinder, a nozzle, through which (by means of compressed air) a stream of powdered coal is projected into the cylinder and there consumed. Total combustion of the powdered coal takes place within a relatively limited distance near the lower end of the cylinder, such distance being perhaps not over 20 ft. The very high temperature necessary for the final clinkering of the cement materials is restricted, however, to a much smaller distance —say about 8 ft. of the length of the cylinder. With cylinders of the dimensions indicated, and providing for total combustion of the powdered coal in approximately the distance mentioned, about 2800 lb. of cement clinker are produced per hour with an expenditure of about 800 lb. of coal dust, the maximum temperature reached being approximately 3000° F. The gases of combustion are swept forward in the cylinder and impart their heat to the advancing material, finally finding their exit through a stack at the feed end at which the cold material is introduced. The compressed air for projecting the powdered coal through the nozzle into the cylinder being insufficient to effect its complete combustion, the additional air necessary for that purpose is introduced through the exit orifice for the burned clinker. This supplementary air is drawn in by reason of the draft created by the stack and by the compressed air. The small amount of material which passes through the cylinder has so limited a capacity for the absorption of heat when it enters the contracted zone of high temperature that it effects very little lowering of temperature. In practice it is necessary that the temperature in the contracted zone, or in the zone of effective clinkering, should not vary except within narrow limits. If the temperature is too low the chemical reaction necessary to form good cement does not take place, or only partially so; while on the other hand if the temperature is too high the clinker will be nearly melted, and when thus over-burned, undesirable chemical reactions take place, making an improper cement. If with the proper proportions of coal and air, adjusted to produce the desired clinkering temperature, the amount of material fed into the cylinder is doubled, with a corresponding increase in the amount of fuel and air, then twice as much coal will be burned in substantially the same distance, and the temperature will therefore rise to so great an extent that the material will be over-burned and the fire brick lining of the cylinder will suffer injury. The additional amount of material fed will not be sufficient materially to lower the temperature in the clinkering zone, and hence with usual cylinders as now arranged and operated the output is nearly fixed and cannot be exceeded."

The Edison invention covers a method by which the output of material, with burners of the type described, can be very greatly increased. This is accomplished by altering the conditions of combustion and extending the area of high temperature, i.e., the clinkering zone, over a greater length of the cylinder. The kiln is thus enabled to burn a very much greater amount of fuel, and carry through the cylinder and properly burn a very much greater amount of cement or other material, without raising the temperature in any part of the zone of maximum heat above that required to secure proper results. To this end there are employed two or more combustion zones within the cylinder, each providing for a zone of clinkering heat. The point of maximum temperature of one zone is preferably made closely adjacent to the point of maximum temperature of the second zone, so as to secure anywhere between such points a sufficiently high temperature to obtain the desired clinkering effect.

In this way it is possible to secure within the burner a much larger proportional area of effective combustion with relation to the quantity of fuel used than is now possible.

To illustrate the principle generally, assume two nozzles to be employed, one being supplied with powdered coal and air at say, 50 lb. pressure per square inch, which serves to throw the fuel with great velocity into the cylinder, so that the center of its zone of combustion is say, 25 ft. from the exit end of the cylinder: and the other being supplied with coal and air at say, 20 lb. pressure, so that the zone of combustion thereof will be located between the first zone and the exit end. The columns of air and powdered coal from the nozzles, on account of their great velocity, pass into the cylinder for a considerable distance before spreading and before the temperature of either reaches the combustion point. By employing a number of nozzles, supplied with air at different pressures, and with the proper amount of coal fed into each, a very large amount of coal can be burned; and the extent of the zone of clinkering temperature may be increased. Thus the output of finished material may be largely augmented. In this way a considerable saving is secured in investment and operating labor per ton of output; while an additional saving is secured in the dimunition of the amount of coal necessary to burn a given amount of material, because of the diminished loss by external radiation.

In other words, by directing the different columns or streams of powdered coal within the cylinder so that the areas of combustion will, so to speak, " overlap," it is possible to secure an additional area of clinkering temperature or an additional zone of high heat; which cannot be secured with a single burning column of fuel or with a plurality of such columns of fuel separated to too great an extent.

KILN CALCULATIONS

Adequate drying of the coal is generally considered essential, although for some small plants the writer has seen kilns in operation on coal which had not been dried. Wet coal has a detrimental effect on feeding and on the capacity of the kiln. The effect of the moisture, however, depends upon the kind of coal, so that no limit can be definitely stated as essential to success in advance of a trial.

According to Carpenter, the weight of powdered coal required per barrel of cement varies somewhat with the character of the kiln and the character of the process. In the *dry* process of manufacture, the weight of coal is from 83 to 100 lb. per barrel of cement. In the *wet* process the coal varies from about 35 to 50 per cent of the finished product, that is, from 133 to 190 lb. of coal per barrel. The theoretical amount of coal required disregarding the heat due to the formation of silicates of lime and alumina, is probably not far from 30 lb. per barrel, provided 10,000 B.t.u. per pound of coal are utilized. Continuous *stationary* kilns are reported as consuming 12 to 16 per cent of fuel of from 45 to 60 per barrel of cement.

" The capacity of the modern kiln in barrels per twenty-four hours when operating on dry material with flue gases at about 1000° F. may be approximately expressed by the following formula:

$$C = \frac{D^2L}{24},$$

where C = capacity in 24 hours, in barrels of 380 lb.;
D = outside diameter in feet;
L = length in feet.

" The economy of the kiln has been increased by increasing its length. This is due in part to a change in process of burning: the CO being driven off from the material before it reaches the combustion zone in the kiln: and in part to a reduction of losses. The saving due to the use of a 150-ft. kiln in place of a 60-ft. kiln has exceeded 20 per cent in fuel, and in addition has cut down the labor required in operation more than one-half. Kilns can be operated with a stack temperature of less than 1000° F., but in such event the capacity is lessened and the result is generally an increase rather than a decrease in cost.

" Mr. Richard K. Meade, in his book on Portland cement, gives the following calculation as to the heat necessary per 100 lb. of raw material:

		B.t.u.
Heat required:		
Decomposition of 75 lb. CaCO	75×784	=58,800
Decomposition of 4 lb. MgCO	4×384	= 1,536
		60,336
Heat supplied:		
Burning of 0.3 lb. sulphur	0.3× 4,050	= 1,215
Burning of 0.8 lb. carbon	0.8×14,540	=11,632
		12,847
Balance to be supplied by fuel:	60,336 12,847	
	47,489 B.t.u.	

" About 600 lb. of raw material are needed per barrel, so that the total heat required per barrel would be 284,934 B.t.u., disregarding the effect of the silicates. The combination of the silicates and lime gives off heat. The amount is in doubt as the exact resulting composition of the silicates is not known. A certain combination might produce 44,700 B.t.u. per 100 lb. of raw material; this is hardly possible as it would reduce the heat to be supplied to 2789 B.t.u. per 100 lb. of raw material or to 16,734 B.t.u. per barrel of cement. At 47,489 B.t.u., with coal evolving 10,000 B.t.u., the weight of coal per barrel of cement is $47,489 \times \frac{6}{10000} = 28.5$ lb.

" The principal cause of lack of economy in the rota kiln is the excessive flue loss. Dr. Joseph W. R has reported the following distribution of heat losses in a 6 by 60-ft. kiln:

36 per cent due to excess air in chimney gases,
36.1 per cent due to excess temperature of necessary products of combustion,
10.7 per cent in hot clinker,
12.8 per cent in radiation and convection.

"The above investigation indicates about 72 per cent of flue loss of which one-half is due to poor operation and is preventable.

"In order to utilize the waste heat in the stack, it was arranged in the Cayuga Lake plant to pass the discharge gases of two kilns through a boiler and an economizer, the draft being maintained by a fan. It was also arranged to heat the air entering the kilns by drawing it through the hot clinker discharged from the kilns. The kilns were 60 ft. in length, 7.5 ft. in diameter at the lower end and 6.5 ft. in diameter at the upper end. The results are shown in Table 1.

TABLE 1

TWO KILNS 7½ AND 6½ BY 60 FEET

Coal consumed per hour, lb	1,888
Clinker specific heat, 0.2	
Clinker produced per hour (CaO = 62 per cent), lb	8,018
Weight $CaCO_3$ per hour, computed, lb	8,875
Moisture in raw material, 3.1 per cent	
Weight CO_2 per hour from material, lb	3,660
Weight of air supplied per lb. of coal, 44 per cent excess, lb	16.1
Total weight of air supplied per hour, lb	32,297
Weight of air supplied by coal feeders per hour, lb	5,850
Total weight of gases discharged per hour, lb	37,749
Heat discharged per lb. of gas, 0.23×(1800 − 100), B.t.u	391
Area of outside of kiln, sq.ft	1,213
Area of hood exposed, sq.ft	76
Gas leaving kilns, deg. F	1,820
Air entering kilns, deg. F	480
Gas leaving boiler, deg. F	660
	450
hird, deg. F	2350-2960
art, deg. F	2960-1800

"From the data in Table 1, Table 2 has been computed, showing the approximate distribution of heat throughout the process.

TABLE 2

APPROXIMATE DISTRIBUTION OF HEAT

	B.t.u.	Per Cent.	
Heat entering kilns from clinker cooler....	2,041,000		
Heat entering kilns from combustion of coal	26,450,000		
Heat produced from chemical reactions....	632,206		
Total heat supplied.....................	29,123,206	100.0	
Discharged from kiln to boiler............	14,859,859	51.2	
Discharged with clinker (8018×2×500)...	4,409,540	15.1	
$CaCO_3$ decomposed (8875 lb. at 765 B.t.u.).	6,789,375	23.3	
126 lb. sulphuric anhydride liberated.......	238,140	0.8	
252 lb. water evaporated.................	303,200	1.0	
Radiation and unaccounted for...........	2,523,092	8.6	
Radiation per sq.ft. of surface of kiln per hr..	974		
Heat absorbed by boiler from kiln gases...	8,798,328	30.5	
Heat absorbed by economizer from kiln gases	1,178,998	4.0	
Stack loss and boiler radiation...........	4,882,533	16.7	51.2

"The investigation thus showed that about 50 per cent of the heat was discharged into the stack and of that amount about 68 per cent could be utilized in a boiler and economizer so that the ultimate necessary flue loss was only about 17 per cent of the heat in the fuel."

UTILIZATION OF WASTE HEAT

In the cement industry, very few attempts have been made to utilize the heat of the escaping gases. The reason why the waste heat has not been utilized to a greater extent is, no doubt, the difficulty of arranging and maintaining the waste heat boilers.

Although the temperature of the kiln stack gases has been considerably reduced with the advent of the long kiln, these gases are still discharged at temperatures which justify installations of equipment for the utilization of the heat in the large volumes of hot gases which are constantly discharged from the furnace.

One method of utilizing the heat in these gases stands out prominently on account of the economical results obtained. This system contemplates passing the kiln gases through a rotary dryer placed directly behind the kiln.

Such a dryer should be so proportioned in relation to the kiln that no condition can be produced which will tend to reduce the capacity of the kiln. The diameter of dryer should be at least equal to the bore of the kiln, so that the dryer will not have a dampening effect on the draft. The kiln and dryer should be served by separate stacks, of the same diameter and height, so that the kiln may be operated either independently or in unison with the dryer. The stack chambers serving the kiln and the dryer should be liberally proportioned, so that the gases will not be subjected to any interference as they leave either the kiln or the dryer. Between the kiln stack chamber and the dryer there should be a removable hood, to permit free access to the dryer without interfering with the continuity of operation of the kiln. A rotary kiln discharging its waste gases through a properly proportioned dryer will not only furnish sufficient heat for effectually drying the raw material for a number of kilns, but in addition will produce as much clinker per pound of coal as will the same size of kiln not coupled to a dryer. A kiln 8 ft. in diameter 120 ft. long, coupled to a dryer 7 ft. in diameter and 50 ft. long, kiln and dryer each being served by a 7-ft. stack, 100 ft. high, will have the same capacity and will show the same fuel consumption as an ordinary kiln of the same size discharging its gases of combustion to the atmosphere through a stack of the same dimensions as the stacks serving the coupled units.

CHAPTER VI

APPLICATIONS OF POWDERED COAL TO REVERBERATORY FURNACES

THE losses and nuisances arising from flue dust in blast-furnace smelting, no less than the better fuel ratio and tonnage obtained with powdered coal, are leading to a growing use of that fuel for reverbatory furnaces. The latter type of furnace also furnishes opportunity for the proper handling of converter slag derived from basic ores. The principal difficulty attending this application of powdered coal have arisen from the choking-up of flues by adhering layers of ash: and this difficulty is minimized by using straight flues free from abrupt changes of area. The deposit of a silicious surface over the charge is made impossible if the coal is positively and regularly fed to the furnace.

Two papers on this subject presented to the American Institute of Mining Engineers in February, 1915, describing plants of the Canadian Copper Co., Washoe Reduction Works and Anaconda Copper Co., are reproduced here by special permission of the writers, the late Dr. David H. Browne, Metallurgical Engineer of the International Nickel Co., and Mr. Louis V. Bender of the Anaconda Copper Mining Company.

(*Paper by Dr. David H. Browne*)

CANADIAN COPPER CO.

" The use of coal dust reverberatory furnaces was for the Canadian Copper Co. a matter of necessity, and not of choice. For twenty years smelting had been done in blast furnaces alone, and with the Herreshoff furnaces used prior to 1904 there was no trouble in treating fine ores. But little flue dust was produced, and this, following the time-honored custom, was wet down and put back with the charge. Whether the flue dust was really smelted or whether it was worn out by being chased around in a circle, was a problem that troubled no one.

" With the installation of modern blast furnaces and high-pressure blowing engines in 1904, flue dust commenced to assert itself. Evidently more dust was made than could be smelted, but so many vital problems engaged attention at this time that this minor question was pushed to one side.

" In 1906 details of blast-furnace smelting and the conversion of matte had been worked out to a satisfactory conclusion and the ever-increasing piles of flue dust and fine ore in the stock yard demanded serious consideration. Numerous experiments in sintering, briquetting, mixing with converter slag to form blocks of fine dust with green-ore fines and cement, and so on, were undertaken. None of these showed much promise. The problem was still further complicated by the question of treating converter slag. The ore was basic, the slag was not needed as a furnace flux, and it was felt that under these conditions the old method of pouring slag in molds and remelting in the blast furnace was an unnecessary expense. If the converter slag could be settled in basic-lined reverberatory furnaces, in which (at the same time) flue dust and green-ore fines could be smelted, two problems might thus be solved at once.

" Reverberatory practice with these ores was, however, unknown. As carried out in the West, on silicious ores and concentrates, at least 25 per cent of fuel was required, and even this ratio varied greatly with the skill of the fireman. The lack of skilled labor, the difficulty of recovering unburned coal from the ash by water concentration during Northern winters, and the difficulty of utilizing it, if recovered, in a plant using no steam [illegible] uncertainty of the effect of highly basic charges [illegible] and walls, and entire local unfamiliarity [illegible] practice, caused a postponement of [illegible]

"In the Engineering and Mining Journal of February 10, 1906, Mr. S. S. Sorensen, describing certain experiments at the Highland Bay Smelter, called the attention of the metallurgical world to the possibilities of powdered coal as a reverberatory fuel. While Mr. Sorensen's experiments did not lead to the adoption of powdered coal at Highland Bay, they showed clearly that increased tonnage could be attained with decrease fuel consumption, and that such difficulties as he encountered were largely mechanical and presumably removable. Mr. Sorensen was probably the pioneer in the use of powdered coal in reverberatory furnaces.

"His experiences were supplemented by Mr. Charles Shelby, who in an able article in the Engineering and Mining Journal of March 14, 1908, described his investigation of the use of powdered coal in a reverberatory furnace at Cananea. Mr. Shelby experienced trouble from the sticking of ash in the flues and from the formation of a silicious blanket over his charge; but, until blocked by these conditions, he attained better results, both in tonnage and in fuel ratio, than had been obtained by grate firing. A profitable contract for the purchase of fuel oil led to the discontinuance of these experiments, but enough had been done to show that the subject was worthy of further investigation.

"In October, 1909, the Tepoe Valley smelter (of which Mr. Sorensen was the Superintendent) was visited by the writer. We went over the details of the Highland Bay experiments together and agreed that with proper attention to structural and mechanical details the troubles there experienced would be avoided. In the same month Mr. Shelby was interviewed regarding the difficulties encountered at Cananea. These also seemed avoidable. It was evident that if the problem could be worked to a successful issue, the fuel ratio, then usually about 4 to 1, might be raised to 6½ or 7 to 1. This warranted considerable expenditure in working out the details of practice.

"In visiting all of the prominent Western smelters in that year (1909), it was found that the proposal to use powdered coal on a large scale was received with more interest than enthusiasm. As a rule, investors were skeptical as to the expediency of starting a new plant on a practically unproved method.

" During the fall of 1909 Mr. George E. Silvester visited the cement factories in the Eastern states in order to study the proper method of grinding and burning coal. His report confirmed the opinion that the process was practicable, and during the winter plans were drawn for a reverberatory furnace plant to use powdered coal as a fuel.

" The mechanical difficulties encountered at Highland Bay and at Cananea consisted chiefly of two things, viz.: the stoppage of flues with accumulations of ash, and interruptions and irregularities in the coal-dust feed. It had been demonstrated in cement plants, however, that the operations of feeding and burning powdered coal could be made quite as continuous, as uniform, and as easily regulated as feeding fuel oil; provided only, that proper methods were used in the preparation of the coal.

" A plant equipped with the latest appliances for drying and pulverizing coal was therefore designed, to be located in a fireproof building, entirely separated from the reverberatory furnace building. Especial care was taken to specify that all bins, conveyors, etc., for the powdered coal, be made as nearly dust-proof as possible by the use of rubber gaskets, to eliminate the danger of dust explosions. To circumvent, if possible, the trouble from accumulations of coal ash, an entirely new arrangement of furnace flue was designed, the idea being to eliminate the several right-angled bends in common use, and to provide, as far as possible, a straightway [illegible] r the gases. In following out this idea, the skimm [illegible] s taken from its traditional position at the [illegible] nace and placed on the side, entailing the s [illegible] ly, of nothing but the tradit [illegible]

" As [illegible] aste gases was

not an essential feature of the installation, hydro-electric power being used in the plant, the waste heat boiler was made entirely a secondary consideration, and was situated so as not to interfere in any way with the straightway idea, whether in use or by-passed.

" In February, 1910, in company with Mr. Silvester, the Western smelters were visited to obtain information on reverberatory practice. Mr. Sorensen was keenly interested in Mr. Silvester's plans, in which he advised a few modifications of minor details, while approving the ideas as a whole.

" In April, 1910, the Canadian Copper Co. authorized construction, and work was begun at once. As the entire site of the proposed plant had to be raised 11 ft. above the yard level, and a large amount of rock cutting and filling was necessary on the hillside where the bins and approaches were planned, active construction did not commence until December 23, 1911.

" As built, the original furnaces were lined with basic brick, and the hearth was an inverted arch of magnesite. The furnaces went into operation before any means of drying the flue dust was provided, and during the winters of 1911 and 1912, a large amount of charge, wet and frozen as it came from the piles, was shoveled in through the doors of the furnace. All the converter slag was poured in; at first through a door near the fire end, just as scrap is charged in an open-hearth furnace.

" The introduction of so much cold air and cold material made it impossible to attain any satisfactory fuel ratio. During the first five months, 21,406 tons of cold charge and 43,463 tons of converter slag were smelted with 9609 tons of coal. This shows a ratio of 6.7 tons of total charge per ton of coal, but of only 2.2 tons of cold charge per ton of coal. However, as the cold charge was wet and often frozen, better results could probably not be expected.

" The combustion of fuel was satisfactory from the start, no trouble being experienced either in grinding or in burning the coal. The ash, while working on cold charges, choked and clogged the flue at the throat. This difficulty was not eliminated until later, when hot calcines were used and a larger tonnage was smelted. In general, the more slowly the furnace worked, the colder was the ash and the more it stuck and accumulated; while the faster it was driven the less did the ash hang back in the furnace. Under present conditions, with rapid smelting, the ash is a negligible factor.

" In the summer of 1912 the roof and side walls were repaired, and some facilities provided for drying the charge. In the winter of 1912 four wedge furnaces were built to roast green-ore fines. These went into operation in March, 1913. At this date we ceased to run converter slag in the reverberatory furnaces, since with the opening of No. 3 mine the blast furnace charge became more silicious and slag could be used economically as a flux.

" During the next year very pronounced improvements were made by Mr. Agnew, then Superintendent of the smelter, who with his foremen, Messrs. Kent, McAskill and Mason, worked out and adapted to our use a modification of the Cananea system of side-fettling. Long and shallow pockets were provided along the side wall, through holes in which the green-ore fines were fed to protect the sides. This naturally led to bricking up all the doors on the furnace, and marked improvement resulted from the exclusion of cold air and the insulation of the walls by a non-conducting and continuously renewed blanket of fines.

" As the walls were thoroughly protected by the charge thus introduced, the use of basic brick in the walls and hearth was no longer necessary, [illegible] change, in October, 1913, was to the silicio[illegible]alls customary in Western smelters.

" In 1914 the [illegible]ctice were steadily improving. [illegible] months in 1914, one revert [illegible] in the tabulation below.

1914—CANADIAN COPPER COMPANY

	January.	February.	March.
Furnace, days	31	28	31
Calcines, tons	10,020	9,460	10,860
Blast furnace, flue dust, tons	906	922	847
Wedge furnace, flue dust, tons	171	193	180
Converter slag, tons	69	248	0
Green-ore fines and samples, tons	1,731	1,326	2,308
Total charge, tons	12,897	12,149	14,195
Coal, tons	2,575	2,150	2,094
Charge per day, tons	416	434	458
Coal per day, tons	83	77	67
Ratio of charge to fuel	5.0	5.65	6.77

" In the summer of 1914 a change was made in grinding the ore fines for the wedge furnace. The ore, which was previously too coarse to make a good calcination, was treated in ball mills, and screened, so that only about 14 per cent remained on a 20-mesh screen, instead of the former 40 per cent. This finer-crushed ore could not be produced in sufficient quantity to keep the furnace up to its capacity. Furthermore, when the calcines dropped, on account of this finer grinding of the ore, from 13 per cent of sulphur to 7 or 8 per cent, the production of slag increased and the production of matte fell off. These conditions, with the shortage of calcines, militated against a high ratio of charge to fuel, and in June, 1914, the fuel ratio was 5.35.

" The above narrative is introduced to show the gradual development of the process, and the conditions which have brought about changes from the original plans. We now consider some details of construction.

" The area occupied by the reverberatory-furnace building was raised about 11 ft. above the surrounding yard by pouring furnace slag between concrete retaining walls, which were protected as the filling progressed by spreading clay against the concrete. At distances of 56 ft. apart, on the center lines between the furnaces, tunnels 12 ft. wide were provided in this slag foundation. These tunnels were to carry tracks so that the reverberatory furnaces built on this poured-slag area could be tapped into pots at the level of the yard. The furnaces are skimmed into 25-ton pots at the yard level. (Figs. 27 and 28.)

" Under the lines where the furnace side walls were to go, concrete footings were introduced, and between these footings transverse rods were laid in iron pipes. Then the slag pouring was continued. The tie rods carried anchor-plates which held the footings under the furnace walls together and took up the lateral thrust at the foot of the side buckstays. Under the furnace hearth, the slag filling rose 12 in. above these concrete footings. On the concrete footings were erected the silica-brick furnace walls.

" The horizontal dimensions of the furnace are 23 ft. 6 in. by 116 ft. 9 in., outside of the brickwork.

" The side walls arising from the footings inclose 12 in. of poured slag which extends under the silica hearth. The side walls are carried up 27 in. in thickness to a height of 3 ft. 4¾ in., making the total height of the side walls 8 ft., 9¼ in., up to the point where the cast-iron skew block is laid for the arch roof. This height is maintained for a distance of 34 ft. from the fire end, from which point the skewbacks slope down to correspond with the slope of the arch roof referred to above.

" The end or fire wall is 3 ft. 6 in. wide at the bottom for a height of 2 ft. and is then stepped back to 22½ in. at a height of 3 ft. 8 in., and again stepped back to a width of 13½ in. at a height of 6 ft. 3 in. At the other end of the furnace, commonly called the skimming end, or front, the construction is very heavy, to resist the end thrust of the hearth. It consists of a brick block, 6 ft. wide and 3 ft. high, which is stepped back to a width of 2 ft. 6 in. at the throat, at which point it is 4 ft. 9 in. high.

" The roof at the fire end is of 20-in. silica brick. The

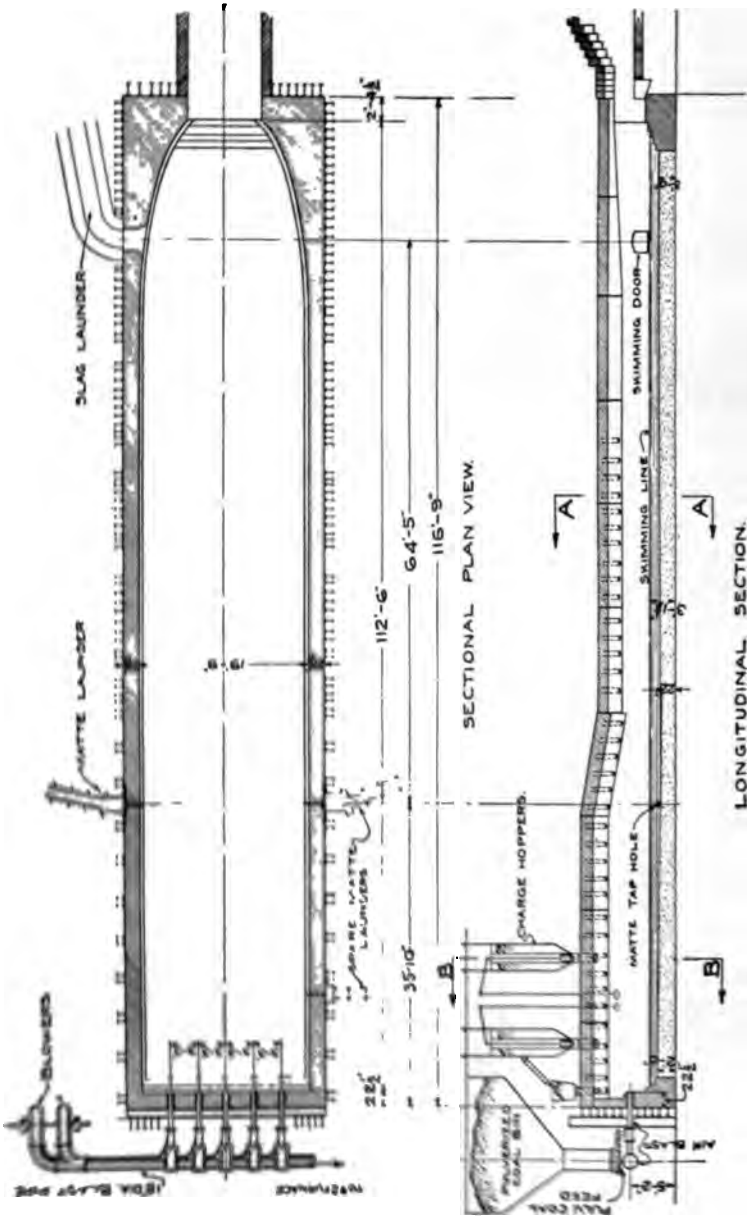


FIG. 27.—Reverberatory Furnace Using Powdered Coal.

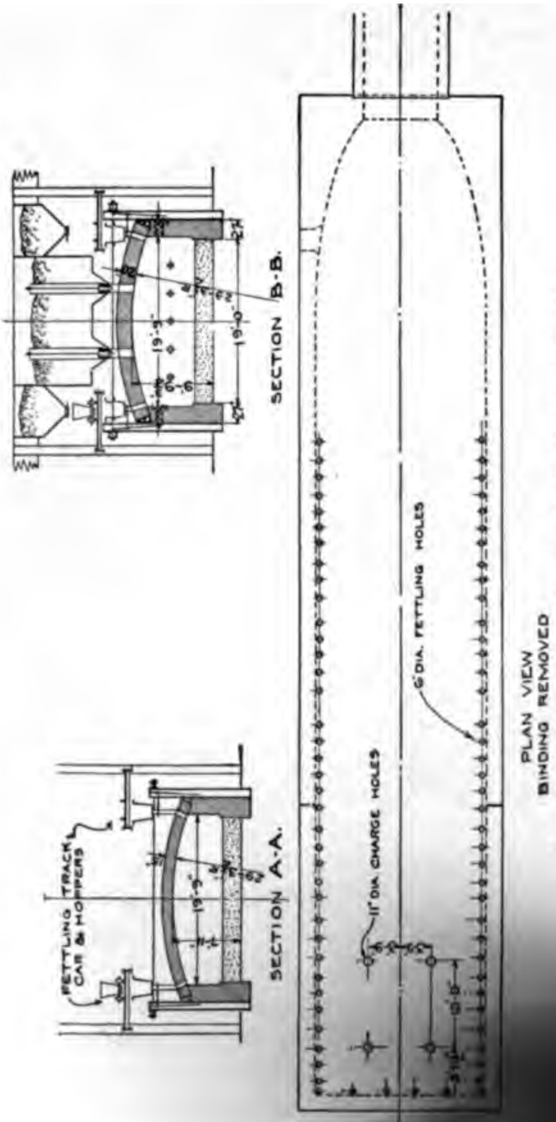


Fig. 28.—Reverberatory Furnace Using Powdered Coal.

height at the skewback is 7 ft. 9¼ in. above the bottom of the quartz hearth. The central line is 9 ft. 9¾ in. above the same point. The radius is 29 ft. 3½ in. on the under side of the arch.

"When the hearth is in, the inside arch at the center is from 7 ft. 9¾ in. to 7 ft. 11¾ in. above the top of the hearth and about 6 ft. 8 in. above the skim line, or 4 ft. 8 in. above the center line of the coal dust nozzles.

"This height of arch is maintained for a length of 34 ft. from the outside or fire wall. In the next 12 ft. the arch drops 22¾ in., giving a height of from 5 ft. 11 in. to 6 ft. 1 in. above the top of the hearth and about 4 ft. 10 in. above the skim line. This height is continued straight through to the throat of the furnace.

"The 20-in. silica arch bricks are used for 34 ft. on the straight arch and for 12 ft. more on the sloping arch. The remaining portion of the roof is of 15-in. brick. As the height of this roof has been changed at various times, the heights given for the roof at various points are not exactly correct at present.

"There are no side doors to the furnace. As originally built, doors were set on 12-ft. centers, but these have been filled up, so that the side walls present a continuous face of silica brick 22½ in. thick.

"The hearth is silica sand tamped in place. No binder has been used, though better results might have been obtained had some base been introduced. After about five days firing, 50 tons of high-grade matte were put in to saturate the bottom. If steam from the silica sand came through the walls the heat was cut off for twenty-four hours to allow the moisture to escape. Some patches of bottom floated up, but not enough to interfere with subsequent operations. This bottom is almost flat, being 24 in. thick at the end walls and 22 in. thick at the tap hole, 36 ft. from the fire wall. In building the side walls, wood strips were introduced to provide for expansion. These wood strips (¼ in. thick) were placed every four bricks on the inside and between every six bricks on the outside. As these burned out they allowed the brick to expand horizontally. The arch is laid in separate sections 10 to 12 ft. wide, with the usual wooden expansion wedges 2 or 3 in. thick between sections.

" The side walls, built as described, are carried straight to a point 26 ft. from the throat, where they curve inwardly, the space of 19 ft. 9 in. between them being narrower up along the line of gradually increasing curvature to a width of 8 ft. 8 in. at the throat. At this point the opening is 4 ft. 3 in. high at the center and 3 ft. 9 in. at the sides. The arch here is about 4 ft. 8 in. above the skimming line.

" From the throat a straight flue 8 ft. 8 in. wide leads to the waste heat boilers and to the stack. Openings are provided along the side of this flue for cleaning out any deposited ash. An opening opposite the throat is provided by raising the bottom of this flue about 18 in. above the throat and introducing a door in the space thus formed. This is useful for removing any accretions of ash fused in the throat. The skimming door is placed on one side of the furnace, 16 ft. 6 in. back from the throat. This door, 2 ft. 6 in. wide by 15 in. high, allows slag to run off down to a skimming line 14½ in. above the hearth at the tap hole. The slag can rise 6 in. above this line before reaching the level of the side doors now bricked up. Outside the skimming door a cast-iron clay-lined box is provided to trap any matte carried over. From this the cast-iron slag launder curves to a line almost parallel with the furnace and delivers the slag into 25-ton pots, which are brought in on track at right angles to the furnace under the flue.

" The furnace is fe [illegible] rather peculiar way. When
the furnace was started [illegible] of the charge was intro-
duced through two cha [illegible] ear the fire end, as in
usual Western practice. [illegible] r delivered through
two openings, 11 in. in [illegible] 6 in. apart, and 8
ft. from [illegible] ond hopper de-
livered [illegible] fire wall.

" At present almost all of the charge is introduced through hoppers along the side walls. Directly over the side walls, at the fire end of the furnace, large bins are provided, which discharge into small bottom-dump cars. These cars run on 24-in. tracks which are supported from overhead. Under these tracks a long trough runs down each side of the furnace just above the side walls. These troughs are filled from the cars on the track above them. Each trough has openings in the bottom, 2 ft. apart, which openings communicate by a slide gate with 6-in. iron pipes. These pipes pass into holes drilled in the roof bricks, which allow the charge introduced through these openings to slide down on the side walls over which this charge forms an almost continuous blanket. As there are no doors on the furnace, and as the 6-in. pipes are clayed into the openings in the roof, it follows that no air is introduced into the furnace except what is purposely introduced at the fire end.

" These pipes form a continuous line of charging holes, which extend the entire length of the furnace. The charge on the side opposite the slag door is fed all the way to the throat. On the slag side it is fed along as far as the slag door and no farther, as the cold air coming in while skimming cools the walls from the skim door to the throat and obviates the necessity of charging beyond this point. Six similar openings are used in the fire wall.

" The walls are held in place by 12-in. I-beams in pairs, with a space of 5 ft. between each pair, which form the side braces. These are wedged in at the bottom, by wooden wedges, against an iron strap in the concrete footings. The concrete footings are tied together as previously described by 1½-in. rods passing across the furnace.

" The coal dust is introduced through five pipes, 5 in. in diameter. One of these pipes is on the center line of the furnace, the others are in horizontal line with it at a distance of 3 ft. 3 in. from center to center. These pipes are 5 ft. 2 in. above the bottom of the sand hearth, or 3 ft. 2 in. above the top of this hearth. They are about 2 ft. above the skimming line of the charge and the central pipe is about 4 ft. 8 in. below the highest point of the roof.

POWDERED COAL APPARATUS

" The coal as received is ¾ in. and under in size and contains about 7 per cent of moisture. It is dried in a Ruggles-Coles dryer, 70 in. in diameter and 35 ft. long. One ton of coal burned on the grate dries 40 to 50 tons of slack coal to about 0.5 per cent of moisture, which increases to 2.4 per cent of moisture after grinding. About 10 tons of slack are dried per hour of running time. The coal is ground in Raymond impact mills. About 95 per cent passes a 100-mesh and 80 per cent a 200-mesh screen.

" The powdered coal is sucked by a fan to separators above the roof of the dryer building and slides downward into a screw conveyer which delivers it into bins at the fire end of the reverberatory furnace. The dust is fed from these bins by Sturtevant automatic-feed screw conveyers, one for each nozzle, the speed of which can be regulated. These screws carry the dust forward and drop it into the air nozzles about 2 ft. from the point where the nozzles enter the furnace. Any coal delivery pipe can be closed off by a slide gate, and any screw conveyer can be stopped by disconnecting the bevel gears attached thereto. In this way any desired number of the five burners can be run, and at any desired speed within wide limits. The amount of air delivered to each nozzle can be varied at will or cut off entirely.

" As a rule the five burners are in operation. Each delivers about 13.5 tons of coal dust a day or about 19 lb. of coal per minute at the furnace. The total coal blown in is about 67 tons per day.

" The dust drops from the conveyers into the air pipes, which carry it forward into the furnace. The air is supplied by a 4-ft. Sturtevant fan, running at 1300 to 1400 revolutions
ute. The air supplied by this fan is insufficient for
ion of the coal. Openings are left in the end

wall between the coal burners. These openings are stopped by loose bricks, so that the amount of air is readily controlled. The draft at the fire wall is about 0.25 in. of water and at the throat the maximum draft is about 1.2 in. The combustion is very good. One test made for ten days (Jan. 9 to 19, 1914) showed the following averages:

Coal consumption, tons in 24 hours	69.7
Gas temperature at throat, deg. C	922
SO_2 and CO_2, per cent	12.3
Oxygen, per cent	6.5
SO_3, per cent	1.14

" During this test the average charge was 409 tons in 24 hours. This shows a ratio of 5.9 parts of charge to 1 part of coal, but much higher ratios have been attained. The average for March, 1914, was 6.84. This coal ratio depends largely upon the composition of the charge and the nature of the slag produced.

" A criticism might be made of the low temperature of the gases at the throat, 922° C. The usual practice in Western smelters is to carry a temperature of 1200 to 1300° C. at this point, and it might be thought that this low temperature indicates inefficient firing. The fact is that the heat of combustion is utilized in smelting ore along the side walls, and consequently the escaping gases, having done more work than is usually the case, are relatively cold. The function of a reverberatory furnace is to smelt ore, and not to raise steam, and for this reason the more heat that is absorbed from the coal gases in the furnace, the more efficient is the operation and the cooler are the escaping gases.

" The great advantage of coal-dust firing in applications of this sort is the absence of the usual breaks in the temperature curve due to grating or cleaning the hearth, and as a consequence a greatly increased tonnage and fuel ratio. The operation of firing, being purely mechanical, comes under the immediate and direct control of the furnace foreman and responds instantly to his regulation. In addition to this, the peculiar method of feeding by almost continuous charging obviates breaks in the temperature curve due to charging or ordinary fettling. For these two reasons the chart of temperature shows a horizontal line, rising or falling in almost exact accordance with the speed of the coal-feeding device.

" The maximum bath of matte and slag is 22 in. deep. A constant bath of 8 in. of matte is carried. This matte lies 6 in. below the skimming plate, so that after skimming there are 6 in. of slag and 8 in. of matte left in the furnace, making a total minimum depth of 14 in. The skimming door is banked up 8 in. with sand, so that just before skimming the slag is 14 in. deep. As the charge along the side walls occupies a great deal of room there is never at any time more than 40 or 50 tons of slag in the furnace.

" In rebuilding this reverberatory or in designing a new plant, the hearth should be widened to provide for a larger body of matte, which experience has shown to be necessary. As this method of burning coal and of admitting the charge into the furnace bids fair to come into general use, it is expected that many changes, both in construction and operation, will be introduced. There is no doubt that reverberatory smelting along these lines will become cheaper than blast-furnace smelting and that a wider range of ores can be used in such a furnace than in the old style coal or oil furnace."

(*Paper by Mr. Louis V. Bender.*)

WASHOE REDUCTION WORKS

" After investigating the work of coal dust at the Canadian Copper Co. the management of the Washoe plant decided to experiment with and ascertain the advantages of using powdered coal as fuel in their reverberatories. Consequently, during the month of June, 1914, one of their reverberatory furnaces was changed to use powdered coal as fuel. The results obtained by this method of firing are gratifying and show a decided saving in cost of smelting as compared with grate firing of ordinary coal.

" The furnace as remodeled is 124 ft. long by 21 ft. wide, and varies in height from 8 ft. 6 in. at the back to 5 ft. 7 in. at the skimming end. The general construction of the furnace is similar to that of other furnaces at this plant. There are no side doors to this furnace, as it was thought that with the present arrangement for feeding no fettling or claying would be required. The interior of the furnace can be inspected through the burner portholes, after shutting off the burners and giving a few seconds' time for the gases inside the furnace to clear away. The charging is done on either side of the furnace from longitudinal hoppers, extending a distance of 74 ft. from the back end of the furnace. Leading from the hoppers into the furnace are 6-in. pipes spaced 19¼ in. apart, through which the charge is intermittently dropped. The charge is kept well above the slag line at all times; in this way the side walls are protected and no fettling is needed on this portion of the furnace. The remainder of the furnace requires fettling. After operating for three months, it was found that the bricks were eaten into along each side wall from the skimming door back to the point where the charge had been dropped. The depth of this cutting away was 8 in. close to the front end and gradually tapered to zero at a distance of 50 ft., and was greater on the side of the furnace having the larger flue connection. Hoppers will be put in for the entire length of furnace, from which fettling material will be dropped, to prevent this cutting.

" After a run of three months the roof was in excellent condition. At the back of the furnace the bricks were not cut into at all; at 30 ft. from the back end they were eaten away 2 in., but at 60 ft. distant they were as put in. The roof is 20 in. thick. After operating for a while trouble was encountered in tapping the matte. The tap hole was on the east side of the furnace 83½ ft. from the front end. C ing could not be done over the tap hole, or for a distance of several feet on either side; also, owing to the method of charging, matte accumulated in the front of the furnace and could not be completely drained through the side tap hole.

" When the furnace was down for fettling in front, it was seen that the calcines fed into the furnace sloped very gently from either side to the center. This, of course, took up the space which in other furnaces is filled with matte and forced the matte to the front of the furnace and also prevented its being drawn out at the side tap hole. The furnace will not hold more than 50 tons of matte. The other furnaces hold 175 tons. It was finally decided to tap the furnace at the front. A suitable runway was put in and a tap hole made at the side of and below the skimming door, and all of the matte was tapped therefrom. About 35 tons of matte are tapped per shift. The furnace is skimmed three times per shift. The gases are taken from the furnace through brick flues to either of the two batteries of Stirling boilers, each battery developing 650 horse-power. One of the flue connections was left as before, with a cross-sectional area of 13½ sq.ft.; the other flue connection has a cross-sectional area of 40 sq.ft. The smaller flue connection is used whenever it is necessary to clean the boilers connected with the larger flue. This occurs once a month and lasts for a period of three days, during which time the tonnage smelted is considerably less than when using the larger flue. The following figures verify this statement:

Cross-section of Flue, Square Feet.	Average of Tons.	Fuel Ratio.
13½	3 days 405	6.8
40	3 days before cleaning 497	6.7
	3 days after cleaning 539	7.3

ANACONDA PLANT

" The following equipment is installed. It is larger than is required for one furnace, but was installed with the idea in mind of finally equipping the entire reverberatory plant for coal-dust firing.

" The coal from the storage bin is fed into a 30 by 30-in. Jeffrey single roll crusher, where it is reduced to 1 in. maximum size. After passing a magnetic separator, it is elevated and fed by gravity into a 40-ft. by 6 ft. 8 in. Ruggles-Coles dryer. The dryer consists of two cylinders, the one within the other. Blades of angle iron are fastened to the inner side of the outer cylinder and the outer side of the inner cylinder, so arranged that as the dryer revolves the material fed into the space between the cylinders is lifted and dropped onto the inner cylinder and at the same time carried to the discharge end. The outer cylinder at the discharge end extends beyond the inner cylinder and has a revolving head riveted to it; on the inside of the head are buckets which lift the coal and deliver it out through the central casting. It takes a particle about thirty minutes to pass from feed end to discharge end of the dryer. At the feed end the inner cylinder is extended beyond the outer cylinder and, passing through a stationary head, is connected with a fire box. The gases are drawn from the fire box by means of a 72-in. Sturtevant fan, forward through the inner cylinder and back through the annular space between the cylinders to the stack. This exhaust fan is placed on top of the fire box and is connected to the dryer by means of a 30-in. sheet-iron pipe. The fire box is fed with lump coal. The capacity of a dryer depends upon the moisture in the coal and the speed of the fan. With Diamondville coal, 18 tons are dried per hour. During the month of September, 1914, 30 tons of coal were used to dry 1,984.77 tons of coal.

" From the dryer the coal is conveyed by a screw conveyor, and is discharged into a steel bin above the pulverizer, which is in a separate building from the dryer. It is not well to have the pulverizer in the same building with the dryer, for the reason that if an accident should occur, causing the coal to overflow, it might then be drawn into the fire chamber of the dryer and cause a fire, with possible injury to employees.

" The Raymond five-roller mill is used. It has an average hourly capacity of 4½ tons (see Chapter III). A fan is connected to this mill, from which air is admitted underneath the grinding surface. The material is taken away by the air current as quickly as it is reduced by the rolls, and blown into a cyclone dust collector placed 20 ft. above the pulverizer. The mill is thus free of fine material. The collector is of galvanized steel, cone shaped, and has a return air pipe leading from it to the housing around the base of of the mill. A surplus air pipe from this return-air pipe relieves the back pressure and is an outlet for any surplus air that may enter with the feed. An auxiliary collector is placed to receive the dust escaping through this surplus air pipe.

" The finished product is discharged through a spout at the bottom of the dust collector, and is taken by a screw conveyor to a bin placed near to and above the furnace.

" The coal from the bin is introduced into the furnace by means of an air current delivered through five ' burners.' The air current is produced by a No. 11 Buffalo fan at a pressure of 10 oz. and, by means of a pipe carrying a nozzle, is introduced into a 6-in. pipe leading into the end of the furnace. The coal dust, fed from the bin by a screw conveyor, drops upon this nozzle (which acts as a spreader) and is mixed with the air and taken into the furnace. A secondary supply is obtained around the portholes through which the burners are projected into the furnace. These portholes are each 12 in. in diameter, which leaves an annular space 3 in. wide around each of the 6-in. pipes. By means of suitable dampers encircling the burners, this secondary air can be regulated. Another source of secondary air is through four openings between and above the burner ports, the size of the openings being regulated by putting in or taking out brick. The amount of coal fed is determined by the speed of the screw, which is controlled by a Reeves variable-speed regulator. The grinding, conveying, and bin system, from the dryer to the burners, is made as air-tight as possible, with the result that the entire plant is extremely clean and free from dust."

CHAPTER VII

POWDERED COAL IN METALLURGICAL FURNACES

POWDERED coal is manifesting distinct advantages for all kinds of heating operations. With the constant demand for increased output in manufacturing plants, the question of industrial heating, important though it is, is too often lightly considered or entirely overlooked, with the result that worth-while savings in cost of manufacture are not made.

Heat treatment is the basis of many operations in shops and to make it good and cheap requires more than the mere burning of coal or oil. The cost of fuel is not as important as is the question of what can be derived from it; and this depends on how the fuel is utilized. The number of heat units obtained for a cent does not determine the quantity or the quality of the product obtained for a dollar, any more than the price of gasoline determines the cost per ton-mile of running an automobile. If furnaces are so designed as to utilize powdered coal to the best advantage, and the coal dust is economically conveyed, fed and regulated at the furnace, leaving no residue of fine particles of dust on the work; and if the smoke and ash are properly carried away; this fuel meets all reasonable requirements. Powdered coal gives a better and softer heat than any other fuel in use at the present time.

The economy of powdered coal over oil is established, and is probably the one factor that is mainly responsible for the present active interest in its application. Systems have been installed to replace oil where there has been an actual saving of 60 per cent. This is certainly worth while. As compared with producer gas plants, the manufacturers of the latter apparatus bring forward many arguments in its favor; but with an initial l[illegible] 20 per cent or more in the process of manufacture [illegible] is every reason to

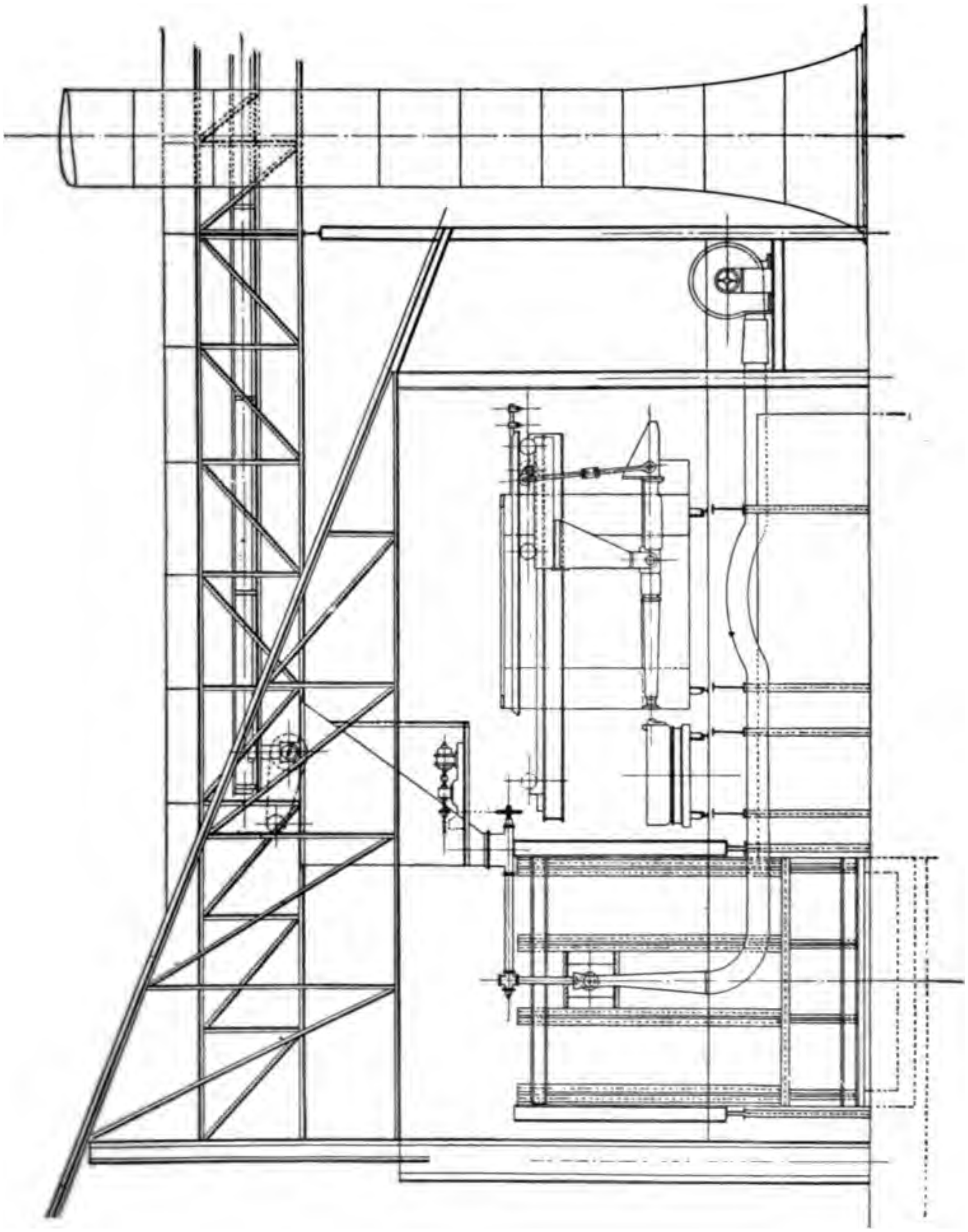


Fig. 29.—Powdered Coal in Open Hearth Furnace.

believe that powdered coal has the advantage. Here every unit of heat is projected into the furnace: and in the furnaces, it is expected, equal efficiencies will be realized from powdered fuel and gas. Producer gas has its place where checker work and ash troubles are objectionable. Where the ash can be taken care of, there seems to be a saving by the use of coal amounting to about 25 per cent.

Some manufacturers of powdered coal installations argue that the proper way to measure efficiency is on a B.t.u. basis. In other words, if a furnace performing a certain heating operation uses 20 gallons of fuel oil per hour, each gallon of oil containing 140,000 B.t.u., there will be consumed 2,800,000 B.t.u. in the operation. On this basis, it will require 2,800,000 B.t.u. in coal in a pulverized state to perform the same operation, the superior efficiency of coal arising from the fact that the 2,800,000 B.t.u. in oil would cost more than the same number of B.t.u. in coal. This fact is obvious; for if fuel oil costs 5 cents a gallon, coal (at 14,000 B.t.u. per pound) would have to be sold at $10 a ton to give an equivalent cost per B.t.u.

But this comparison does not by any means measure the efficiencies of heating furnaces, for the real problem is one of heating cost and not of fuel cost. Powdered coal, or any other fuel, in substitution for what is now in use, should not be chosen for the mere reason that it has a lower B.t.u. cost; but, rather, one must select a fuel which, all things considered, will show the lowest *production* cost under existing conditions in the shop.

Production costs depend on three things; the input, the output and the operator; and in no two shops are these three conditions similar. Each shop, on account of its conditions, requires a separate study to determine what will lead to highest efficiency in heating operations.

In order to determine the efficiency with a new fuel in comparison with a fuel now in use, the following observations should be made:

Start the furnace at the temperature of the room, raise it to a certain final temperature and note the time taken for this operation, both with the fuel now in use and with the new fuel contemplated.

Then take the furnace at the temperature of the room and put in a certain amount of material at the same temperature as the furnace; and raise both the furnace and the material to a certain final temperature, noting the time consumed in this operation, for each of the two fuels in question.

Lastly, start the furnace and material, at the temperature of the room (or at any desired temperature), and operate the furnace in the regular manner. Note how many pounds of material are raised to a certain final temperature, with the number of pounds of coal, oil or gas expanded, in order to perform this operation. Unless the new fuel shows better results in these respects than the fuel formerly used, it is not more efficient, notwithstanding arguments by the manufacturers to the contrary. If powdered coal, tried out in this manner, does not produce effects superior to those from fuels formerly used, it is not more efficient.

At a meeting of the American Institute of Mining Engineers in 1913 Mr. H. R. Barnhurst presented a discussion from which the following is abstracted. The proper method of firing powdered coal is to admit with the fuel the exact quantity of air necessary for the result desired, as shown by observation, and to maintain the relationship between fuel and air as long as the conditions desired are being realized.

This matter of complete control of the two factors, fuel and air, is and will be at the root of all success with pulverized or sprayed fuel in the metallurgical processes.

It is unfortunate that in the present state of our arts it is difficult to obtain exact readings of the temperatures attained in the burning of fuel. We do know, however, that a definite quantity of air will deliver the oxygen required to give the highest attainable temperature from a given fuel. With a knowledge of the components of the fuel, the laws of thermo-chemistry tell us not only the quantity of oxygen we must have, but also the maximum attainable temperature.

Applying these laws further, we learn that any air or oxygen supplied in excess of the ideal requirement simply dilutes the products of combustion and lowers the temperature; also, that insufficient air and oxygen will cause the burning of part of the fuel to CO, and part of it to CO_2. With the air supply halved, we obtain only the poisonous and inflammable CO. However short we may be of pyrometers, there is in the eye of the intelligent operator a gauge which tells him at a glance whether the heat he has is serving his purpose. Pulverized coal is at a great advantage in this respect.

It need not be supposed that an operator must be perpetually adjusting his apparatus. If we find that with the air gate fixed at a certain opening the fire is too hot, a simple reduction in the quantity of fuel admitted changes the ratio of air to fuel and lessens the supply of heat. If the fire is not hot enough, more fuel gives more heat units and a lessened excess of air, resulting in a heightened temperature.

In all probability, some excess of air must always be admitted to keep the temperature from reaching destructive limits. With control of both the quantity and quality of heat, this danger is negligible.

The temperatures used in metallurgical work usually cover a range of nearly 2000°, or say from 2000 to 4000° F. By ordinary manipulation as described, the temperature and quantity of fire can be changed as easily as a gas jet can be turned on or off. The response is instantaneous. This particular feature renders the use of pulverized fuel particularly suitable for metallurgical furnaces. Powde coal is used in all kinds of steel and iron working, incl ore-roasting and flue-dust nodulizing, and in open- furnaces, puddling furnaces, busheling furnaces, h furnaces and forge furnaces.

The main difficulties in the earlier and experimental were caused by: 1, not drying the coal; 2, poor pulv tion; 3, the carrying of too high temperatures; 4, the passages that were too small, giving the gases too high a velocity.

With a knowledge of how much air must be supplied with a given amount of fuel to produce a desired temperature, and a knowledge of the volume of the gases so produced, it is easy to proportion the ports both of inlet and outlet so that a scouring blowpipe effect may be avoided. The excellent practice already attained is undoubtedly due to the application of such knowledge.

Aside from the advantages from the higher efficiency attainable with this fuel, there are a number of incidental factors which in actual service contribute to the profitableness of its use.

The furnace begins its work almost instantly and with whatever degree of temperature intensity may be desired. There are no periods of lowered temperature due to firing cold fuel. There is no cleansing of fires for puddling or heating, so that operation is practically continuous. There is some cinder formed in puddling and heating furnaces: this is disposed of in the usual way. Most of the ash passes out of the chimney and floats away lightly. A neutral ash content within reasonable limits does not appreciably affect the fire.

It has been somewhat difficult to obtain from large users exact data concerning the performance of the various furnaces. Perhaps the best evidence of success is the continuance of use and the enlargement of plants now in operation. The following are authentic data: In roasting carbonate ores of high sulphur content, the carbon has been driven off and the sulphur reduced within permissible limits by the use of fuel amounting to less than 7.5 per cent of the weight of the charge. This problem involves the maintenance of a low temperature, about 2100° F., to prevent the agglomeration of the ore fines into masses. The same practice obtains in the roasting and nodulizing of ores and flue dust, where the temperature must be sufficient to permit the ore to form nodules or balls, but must not be so high as to cause it to stick to the walls of the roasting kiln.

In open-hearth practice with pulverized coal, steel is usually made with this fuel at the rate of from 450 to 500 lb. of coal per net ton of product. This is from an average of 45 heats, the fuel and product being carefully weighed. These figures were obtained during a continuous run of six weeks. The furnace was operating beautifully when visited and no mechanical difficulty had been experienced. The melts were obtained in slightly less time than with oil.

In puddling furnaces, the fuel supply varies with the season, the cool weather of spring and fall permitting a larger putput than when intensely hot weather affects the men at the furnace. It is safe to say that iron can be puddled at an average expense of 1200 lb. of powdered coal per gross ton of muck bar produced; in fact, less than 1000 lb. of coal per gross ton of bars has been shown in practice during periods when favorable temperatures and continuity of work conduced to high economy.

In heating furnaces and busheling furnaces there is some latitude of performance, due to variation in charges placed in the furnaces and in the sizes of mills served by them. The average consumption of powdered coal in heating furnaces seems to be from 500 to 550 lb. of fuel per gross ton. The busheling furnaces require from 550 to 600 lb. To obtain such results, however, the furnaces must be properly proportioned and equipped and in good condition. It must not be expected that the results obtained by simply squirting coal of greater or less degree of pulverization into
a furnace, with an unmeasured jet of air, will equal the
tice here shown. Success implies dry coal, fine p
tion and proper air supply. Another factor is th
tendants should be interested in the productio
results. Men of good order of intelligence,
mechanisms which displace the shoveler and t
barrow man, and who are constantly on the "
both practically and metaphorically, are extrem

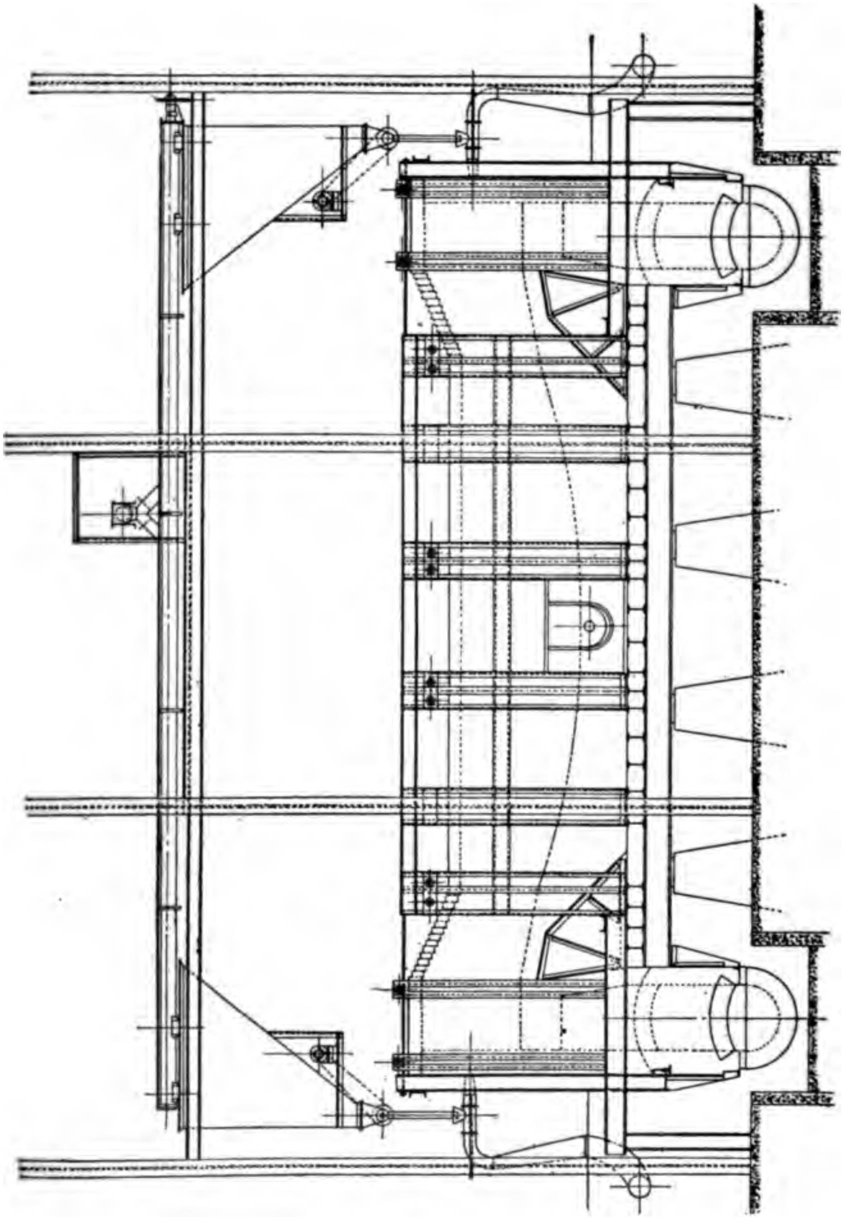


Fig. 30.—Open Hearth Furnace for Powdered Coal.

The operations, however, are simple and the manipulations few and rational in their nature. With such men further advances in economy may surely by looked for.

The procedure followed in the proper preparation of powdered coal as well as in delivering it into the furnace, is as follows (see Chapter III):

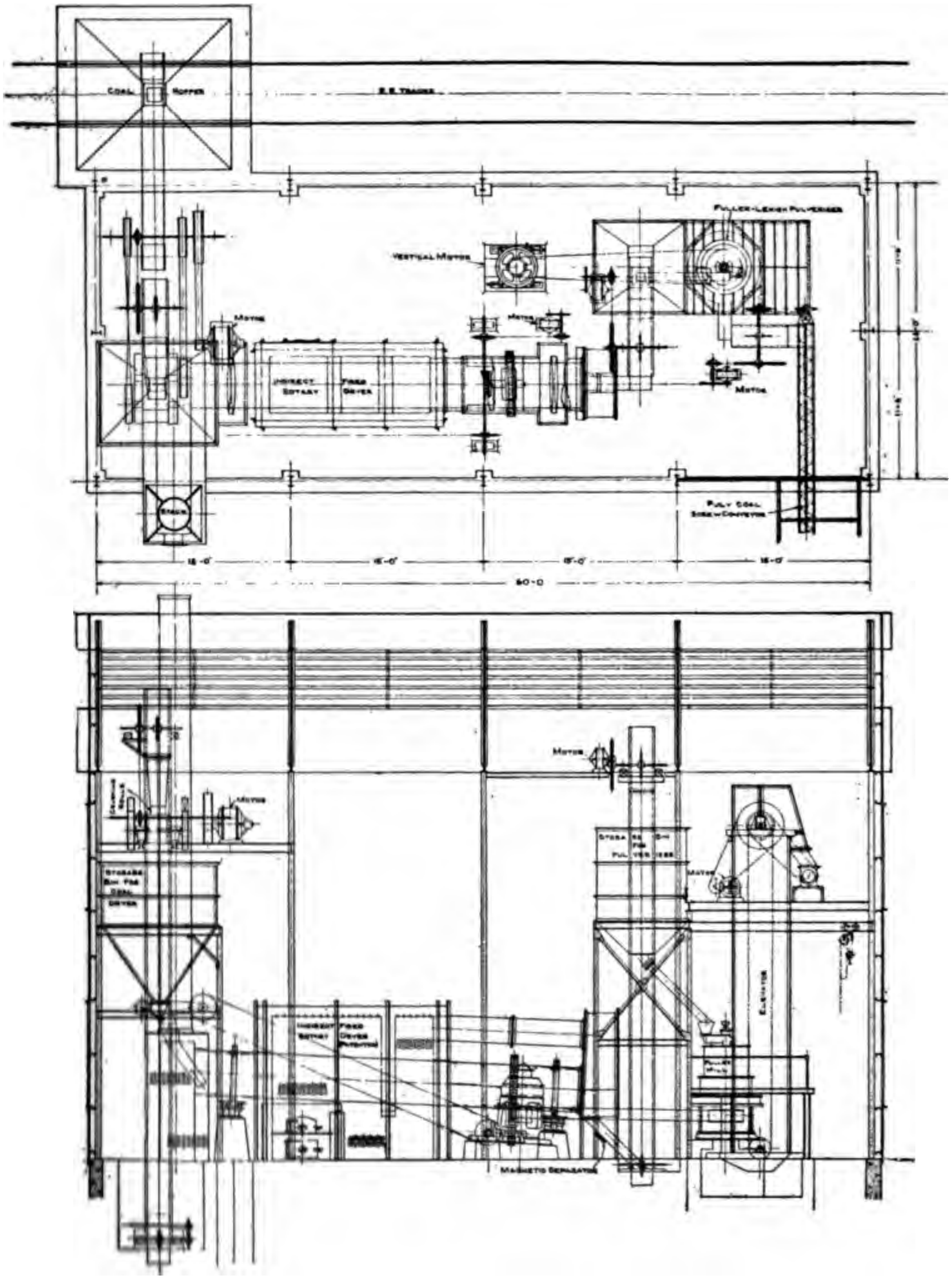
The coal is received in the pit of an elevator, into which it is dumped from the cars. The elevator carries it to the hopper of a pair of crushing rolls. After passing through these rolls the coal may be weighed by automatic recording scales and is sometimes caused to pass over a magnetic separator. The coal is next introduced into a drier to expel the moisture. A good drier of approved design will remove 6 lb. of moisture per pound of fuel used in firing the drier and the product will ordinarily carry less than 1 per cent of moisture. From the pit into which the dried coal falls from the drier, it is elevated to bins above, from which it is evenly fed by spouts and feeders to the pulverizing mills. These mills, if of proper construction, grind the coal rapidly to the degrees of fineness required.

The pulverized coal is led to the pit of an elevator, which carries it aloft to a conveyor which distributes it to the coal bins, from which it is delivered by gravity to pipes leading to the burners.

The bins for holding the coal are proportioned to carry sufficient fuel to serve the furnace during intervals in which the mills may not run; as for instance, coal may be ground and stored for twenty-four hours continuous service by running the mills for ten hours.

The coal is fed from the bottom of the bin by a worm feed-screw provided with a variable-speed drive, so that the furnace may receive fuel as desired. The coal falls freely from the feed-screw delivery through a closed pipe, mixing with the air in its descent in preparation for entering the burner pipe.

The burner pipe is so formed that the air passing through it from a fan not only [illegible] into the furnace,



Figs. 31 and 32.—Fuller Pulverized Coal Plant.

but also, while doing this, acts as an injector, drawing with it the descending column of air containing the entrained coal from the bins above. The fuel is therefore completely mixed with the ultimate column of air while entering the furnace. The speed and volume necessary for proper furnace performance are predetermined from known data.

The air is controlled by the fan speed or by gates, or by both, and the coal by the number of revolutions of the feed screw per minute. The operator adjusts these factors to the quantity and intensity of fire desired, and by inspection at times sees that the conditions remain as required. The construction of the furnace is not materially changed when powdered coal replaces oil or gas. The operating cost in the furnace room is very low, as one man can oversee a number of furnaces. The furnaces are so varied in construction and operation that it would not be possible to describe all of them (see Chapter IV). It may suffice to state that any solid fuel which can be dried and pulverized will reach its highest efficiency in that form, and for this reason fuels hitherto deemed unavailable, such as coke breeze, lignite culm, and anthracite culm, may be now looked to for a cheap source of heat.

In actual practice in the use of powdered coal, the ease with which it is burned has been to a certain extent a drawback rather than an advantage. The novelty of the method is so attractive that those experimenting with it are at first satisfied with producing a good fire with simple apparatus in which may exist no such means of control as are necessary for realization of the highest economy.

It is no success to use twice as much fuel as the work may require, nor is it a success to [illegible] ll fire to a destructive intensity in order to offs [illegible] ning in design. Correct proportioning [illegible] the heat requirements of the job. [illegible] ssary may be ascertained and the [illegible] air supply computed. With [illegible] tion of the volume of the [illegible] have time for its completion. The proper size of ports taking off the gases, the size of the chimney, and the velocities of the gases, should all be as carefully determined for powdered coal as for gas or oil. A simple experiment based on one set of conditions should not be regarded as conclusive.

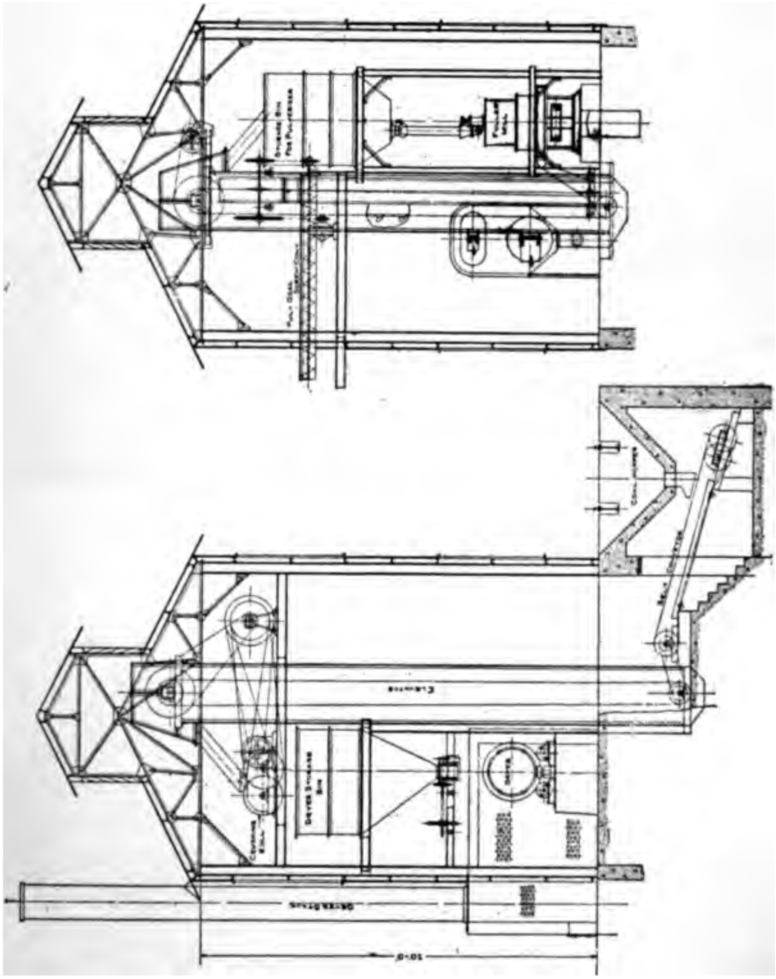


FIG. 33.—Fuller Pulverized Coal Plant.

With proper proportioning of the apparatus, the operation will be elastic and adjustable to a wide range of performance under a very nearly constant percentage of efficiency. This is unattainable in an installation not proportioned for high efficiency. The ease with which powdered coal is burned is no assurance that the best results are being obtained.

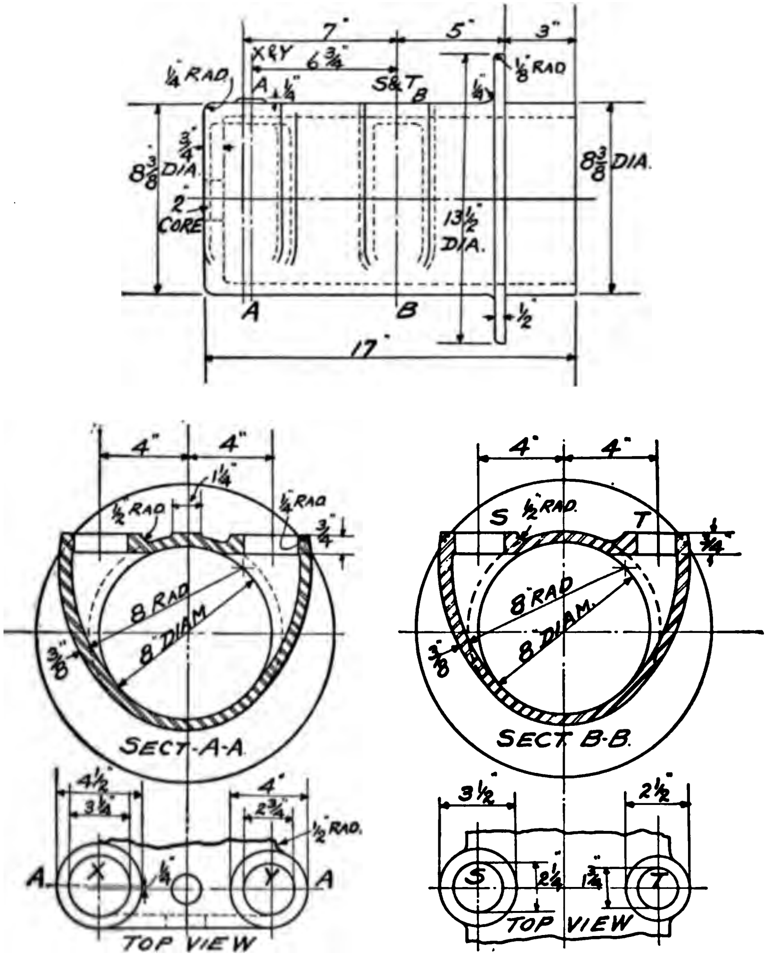
METALLURGICAL FURNACES AT THE GENERAL ELECTRIC COMPANY'S WORKS

The General Electric Company has had a powdered coal plant at its Schenectady works for the past five years, which has been visited a number of times by the author. The information given below was obtained from Mr. A. S. Mann, who had charge of the powdered coal installation, the success of which was due entirely to his untiring efforts. A résumé of Mr. Mann's conclusions appeared in the General Electric Review, and some of the following material is quoted therefrom.

A burner which was perfected by Mr. Mann is shown in Fig. 34 to 36 inc. This consists of a cast-iron cylindrical box, 8 in. in diameter, with five openings beside its discharge mouth. Either of the openings *S* or *T* is used for coal and its primary air, or "carrying" air (40 to 60 cu.ft. per pound of coal dust). Either of the openings *X* or *Y* is used for the combustion air; and sometimes air is admitted at the end, at *U*, also. The first four of these openings are tangential, causing the air currents to take irregular spiral forms, and they are used for short-burning flames.

For an ordinary forge furnace, say 5 by 4 ft., *S*, *Y*, and *U* will be piped up. A fire is started by using combustion air through *Y* alone, for through its use a short complete
mixture can be dropped [illegible] upon burning kindling. As
long as this arrangement [illegible] ved the high heat will be
near the tuyere, perhaps [illegible] t of it. It sometimes
happens that with short [illegible] necessary that a fur-
nace be hot all over and [illegible] if there be a high
local ten [illegible] uniform heat
is wante [illegible] nitted at *U*;

and there is then an immediate change in the character of the fire. The flame is no longer local; the mixture with air is not as good, and burning calls for more time. Coal that



Figs. 34, 35 and 36.—Mann Burner.

can find adequate air near the tuyere burns there; other coal waits till it finds air, and there is a long flame in consequence. By manipulating the air valves at *Y* and *U*, the range of regulation is great and it is possible to make a very long flame; even as much as 30 ft. long under certain conditions. The same thing is true of an oil fire. If mixtures are very poor and oil is sent from the burner in slugs, a flame of great length is attainable; it is only requisite, for a long flame, that the fuel and air travel in parallel streams, whatever the nature of the suspended fuel. Such long flames are not economical; good mixtures give good economy. It must be remembered that the velocity of the stream passing along the axis of the burner should not be so low as to drop the coal. The burner must therefore not be too large, if a short fire is wanted. When two air streams (as at *S* and *Y*), rotating in counter directions, meet, rotation becomes nil and the axial speed must be enough to keep the coal in suspension and preserve the mixture already made. It will be noted that the rotary motion within this burner is just the motion used in a centrifugal separator to draw moisture out of steam, or in a dust collector to separate air from solids. In these devices either the body diameter is large enough to keep the two elements apart, or baffles are provided to trip the heavy material. Moreover, there are separate and guarded outlets for the two components in such devices; none of which is used in this burner. That the device does produce a mixture is shown in its operation; for even when the openings *S* and *Y* are used, causing both jets of air to swirl in the same direction, the flame is only about 24 in. long. As the combustion air at *X* is reduced and the air at *U* is increased, the flame length is increased and combustion becomes slower, showing a less perfect mixture. Some of the furnaces are piped in just that way; and though the range is not great it is ample for most forging work.

For a feeder, the General Electric Co. has found that a simple screw will answer every purpose. The [illegible] draws coal from a supply tank and delivers it in [illegible] to a cavity from which it can be picked up [illegible] air, which carries the fuel along with it. [illegible] feeder is driven by a small motor which can turn at 1800 r.p.m., 800 r.p.m. or any intermediate speed. It is geared down only once. The screw will feed at 300 or 600 turns a minute, or at an even higher speed if required. With so wide a speed control it is possible to carry a fire that shows just a visible red; by a simple movement of a rheostat handle the same fire will spring up vigorously and shortly give heat enough for any forge work.

There is a feature of the plain screw-feed that makes it very convenient in many situations, viz.: it can stand a little back pressure; so that the discharge distances may be long.

In this installation the coal is fed across the shop underground; the supply tank with its feeders and motors is above ground. The coal is carried 90 ft. or more, then up to a furnace and its burner. The distance could be greater, even several hundred feet, and the control would be just as convenient and exact, because the switch and rheostat are located at the side of the furnace and the operator has no occasion to come over to the supply tank. In all of these long transmissions there will be a little back pressure at the screw. Primary air is introduced on the eductive principle, using the fitting shown in Fig. 37. The resistances on the discharge side increase with the distance. If the distance is short, there is a negative pressure in the pipe leading from the screw to the opening *A* (see Fig. 38). Eight inches of vacuum, by water column, is easily attainable. As the discharge distance increases, with the addition of elbows and crooks, this vacuum falls; it may totally disappear, and there may exist as much as 4 or 5 in. of pressure. A plain screw is little affected by these changes, for the throat fit at *A*, Fig. 38, is machined so that a certain impetus is given to the coal. The long distance transmission has been so proportioned, however, that the static pressure is usually negative, say 1 in. or so of vacuum.

The feeder box and the screw are shown in Fig. 39 and Fig. 40 respectively. While usually only a small amount of power is needed to turn the screw (it can be turned with

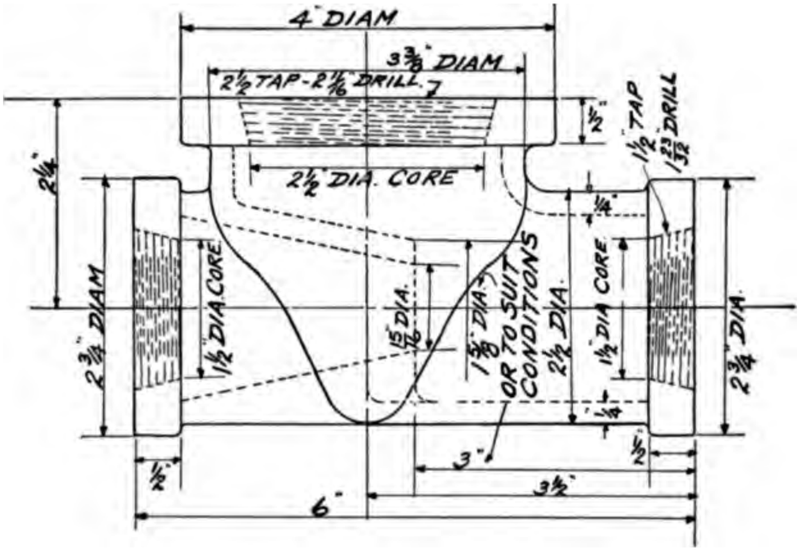


Fig. 37.—Fitting for Introducing Primary Air

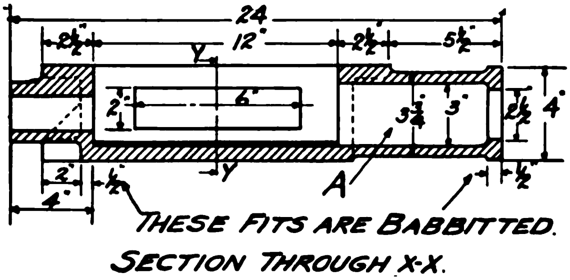


Fig. 38.—Feeder Box—Longitudinal Section.

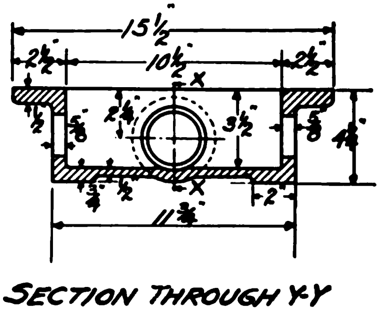


Fig. 39.—Feeder Box—Cross Section.

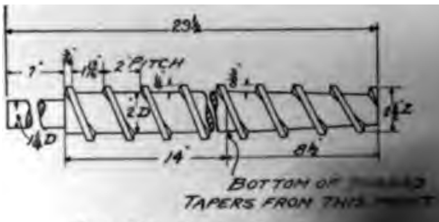


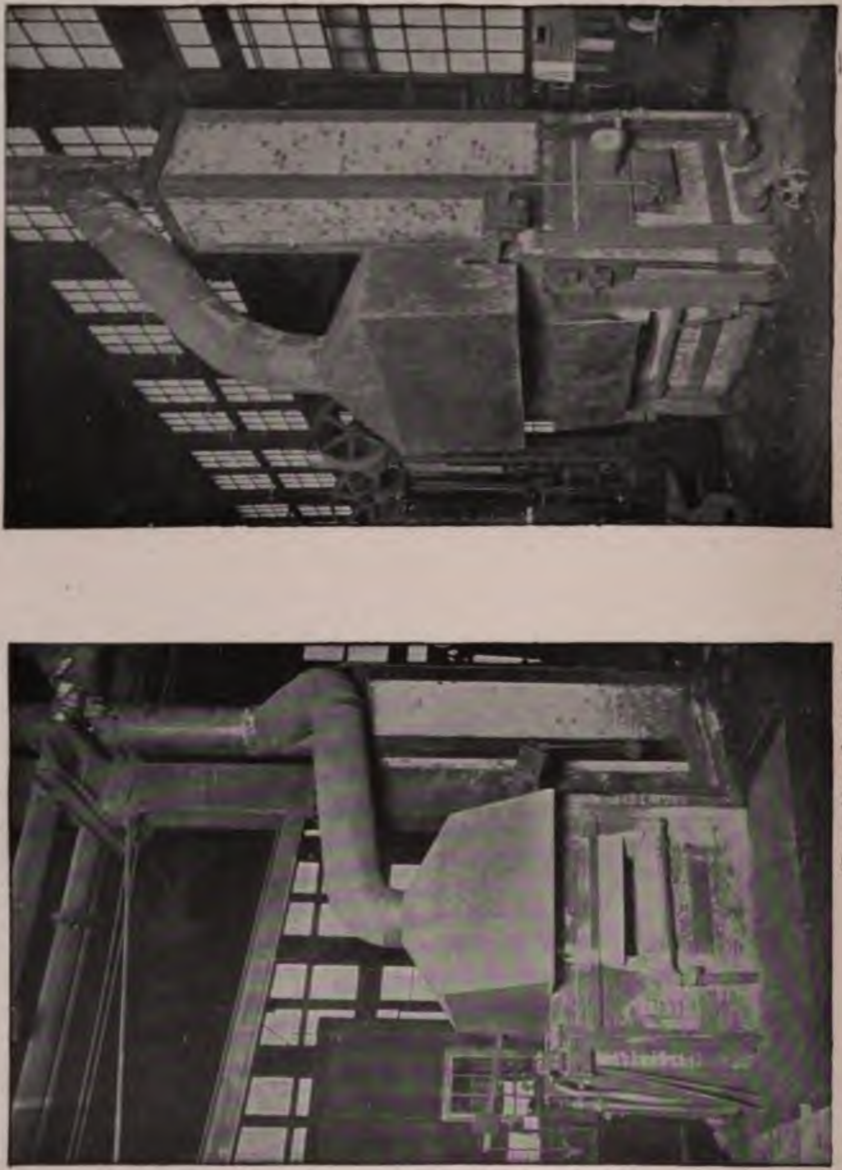
Fig. 40.—Feeder Box Scr[illegible]

the finger fast enough to carry a moderate fire) there are times when a considerable amount of power is required. Normally the coal is light and fluffy, but under certain conditions (as after long standing) coal packs so tightly that no mechanical device can move it. The screw is cut in a lathe with spaces proportioned to the quantity required. A 2½-in. diameter screw, as shown, will feed 700 lb. per hour, and with slight modifications much more. The bottom of the thread is tapered so that, after the screw has "taken its bite," the volume increases as the threadful advances, and the flow to the pipe is free and easy in consequence. The weight of a cubic foot of powdered coal may be anything from 29 lb. to 50 lb. When delivered by a conveyor screw to a tank 7 ft. deep and then measured immediately, it weighs 31½ lb. per cubic foot. In twenty-four hours it will reach 35 lb. and it then increases in density until within six weeks (without jarring) it will weigh 38½ lb. These changes will take place in a container with smooth sides with a diameter equal to half its depth. In a piece of 6-in. vertical pipe 10 ft. 6 in. long, it was found that there was little settlement even after two months. The weight of coal in the tanks is computed at 35 lb. per cubic foot. Sometimes the coal flows as freely as a liquid and will spread out so that its top surface is nearly level in the tank. At other times it will not even flow down hill, though it always moves freely enough unless it has been stopped for forty-eight hours or longer.

This tendency to pack and clog is due to the physical arrangement of the particles through settlement rather than to moisture. Powdered coal will absorb microscopic particles of water, but it cannot be made wet by throwing water upon it. It is impossible to make a paste by using sticks to stir the coal into water. The only way to make a mixture is to take a little coal and water between the finger and thumb and knead the two together. In a day or so this water evaporates, leaving the coal clean and dry.

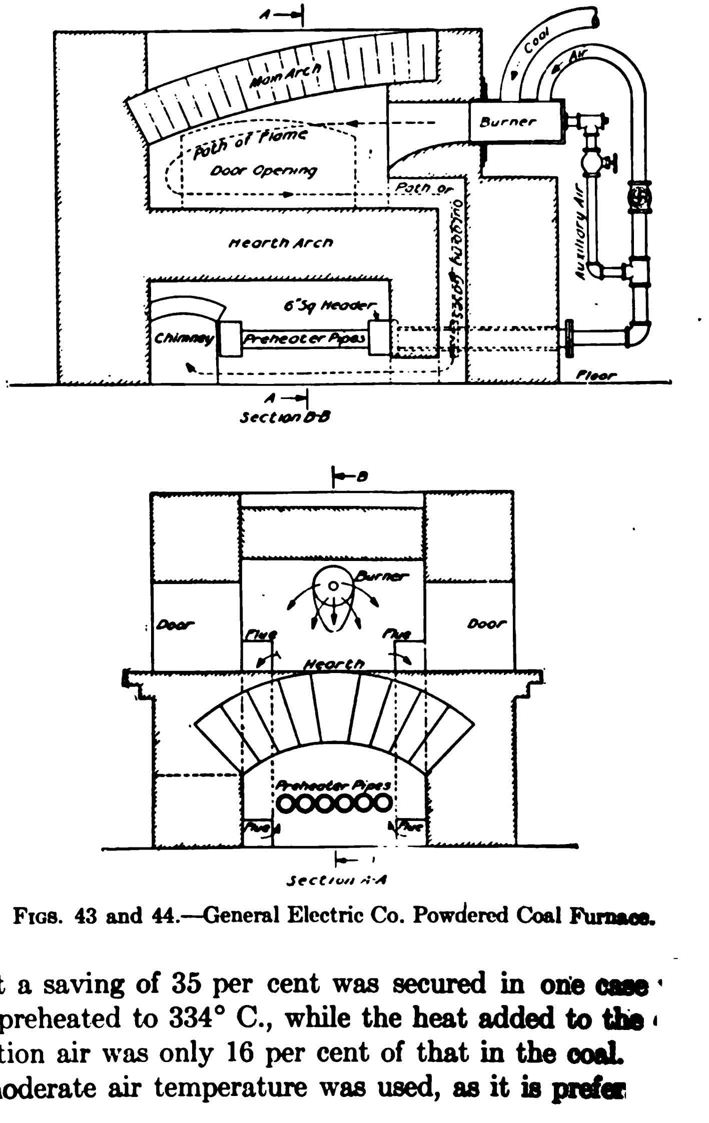
It is not difficult to dry the coal to ½ of 1 per cent of moisture or less, but there is always some small portion that contains moisture in excess. It is surprising to find an 8-ton bin of coal that has been nicely dried dripping with water twelve hours afterwards; but it does so, and it is not an uncommon thing to find a pulverizer frozen up with water in the morning. The source of such water is not hard to find. When coal is in a dryer it is hot and so is the contained air. The air is saturated with moisture at the temperature of the dryer and when the coal and air cool the moisture is precipitated, and in cold weather makes its presence felt. It thus appears that coal cannot be made thoroughly dry through the agency of high temperature.

It is often asked whether an oil furnace can be successfully changed over to use powdered coal. This has been done at the General Electric Company works in the following manner: a coal furnace needs one or sometimes two burners. depending upon the size and kind of work that it is doing. An oil fire make no visible smoke and there is little or no odor from its products of combustion, so there is no reason why there should be a chimney or (in many cases) even a furnace vent. Flames and hot gases can be brought up to, and passed out of, the door, keeping the fronts hot. A coal fire yields no black or colored smoke, though the gases contain some small particles of white ash; but it does have a decided and disagreeable odor. It is better then to provide a hood over the furnace door; enveloping it, if heat is wanted right at the door as it is in most forge work; and this hood must have an outdoor vent. If all gases are allowed to escape in this way, the heat distribution is not perfect, and therefore it is best to use a chimney vent at an appropriate point. It is good practice to run this chimney up throug [illegible] over each furnace and to cut into it a 45° Y [illegible] nd vent is attached. An upward draft [illegible] t by the chimney draft. Figs. 41 [illegible] nnections. It pays to provid [illegible] be adjusted with precisio [illegible] thread the



FIGS. 41 and 42.—General Electric Co. Powdered Coal Furnace.

tips can be moved $\frac{1}{50}$ in., though such extremely fine adjustment is not usually needed. It also pays to preheat the combustion air. The saving in fuel greatly exceeds that represented by the heat imparted to this air. It was found



FIGS. 43 and 44.—General Electric Co. Powdered Coal Furnace.

that a saving of 35 per cent was secured in one case
air preheated to 334° C., while the heat added to the
bustion air was only 16 per cent of that in the coal.
a moderate air temperature was used, as it is prefer

install only such surface as can be readily cleaned, and the low temperature prevents the burning-out of the preheating surface. It is good practice to allow 15 sq.ft. of surface in a furnace that burns 100 lb. of coal per hour, with an inside temperature of 1355° C.

The preheater is made of 3-in. cast iron soil pipe, six lengths being rusted into a header at either end, and placed beneath the hearth in the path of the waste gases.

Two vertical sections of a furnace which is used in the General Electric works are shown in Figs. 43 and 44. The hearth is 43 in. long and 24 in. deep, though this same design is used for furnaces having twice the area.

Furnace Lining. An important part of the subject of furnace construction, which must not be overlooked, is the durability of the furnace. In the metallurgical arts, when extreme heat is a feature of the operation, care must be taken to avoid destroying the furnace by its own operation. This is not difficult. Much of the trouble has arisen from the gases impinging upon the furnace walls at points where changes of direction of gas travel are necessary, and from too high a velocity of gases, due to contracted areas for passage.

Powdered coal is destructive because of concentrated heat of blowpipe tendency, wearing effect due to the impinging of the coal, and the tendency of the ash and brick to flux together. These objections are partially overcome by the use of low air pressure, introducing the coal at a very low velocity, spreading the flame over as large an area as possible, and the cooling of brickwork by water circulation. Where the fuel blows against a bridge wall, the latter requires frequent repair. There has been a gradual reduction of air pressures from 20 lb. on the cement furnaces of early days down to as low as ½ oz. on metallurgical furnaces. This drop in pressure has been due to an effort to avoid the destructive effect of the heavy blast of powder against the brickwork. Where low pressure is used, it must be applied close to the furnace, for 4 oz. of pressure is necessary to carry the fuel through even a short length of pipe.

If the utilized heat is largely absorbed from the gases by the charge, the waste gases will be proportionately less active in scouring the brickwork. In almost any construction (except perhaps a rotary cement kiln) it is found necessary to change the direction of the gases in their progress toward the flue. This change of direction causes the gases to impinge upon the diverting bricks with an energy proportional to their velocity. The brick can be fully protected at these points by a system of water-cooled pipes imbedded in the walls. The brick may fret away somewhat until the area of protection is reached, after which further progress is arrested.

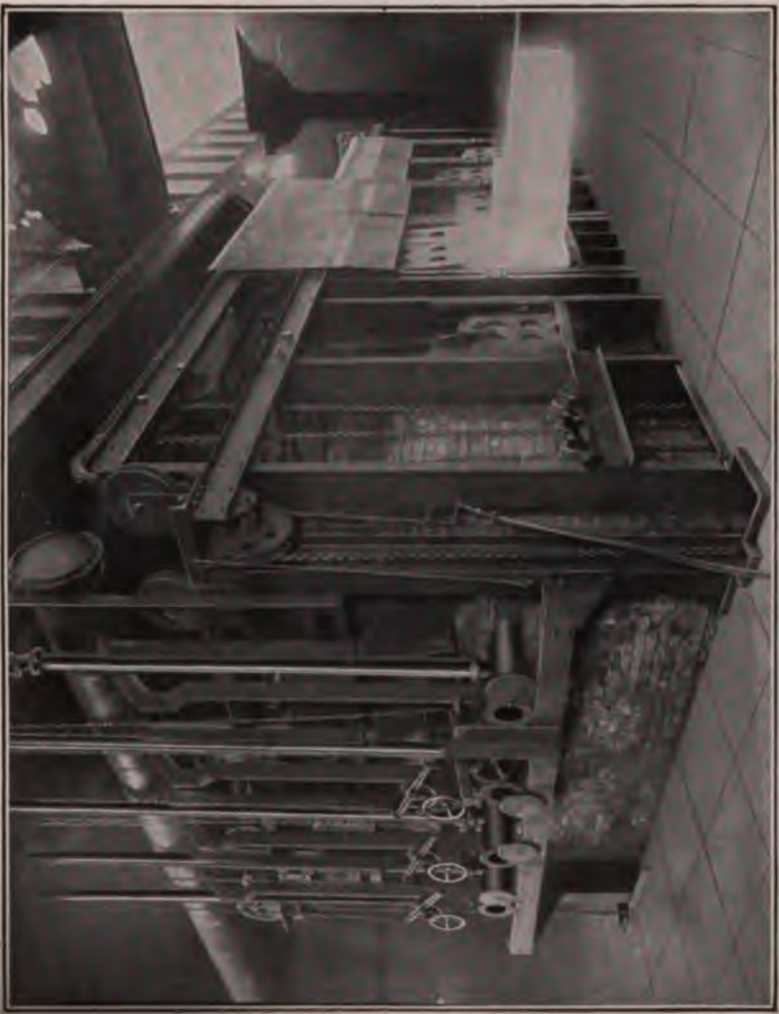
The surprisingly small amount of water which it has been found necessary to introduce, while maintaining the outlet below 200° F., proves that the cooling effect is limited to a prevention of cumulative action and is not perceptably a drawback upon efficiency. Of course, the piping must be so arranged that no air or steam pockets shall exist and so that the circulation will be proportional to the heat stimulus.

At the General Electric works, furnace linings have occasionally been burned out by powdered coal fires. Sometimes a wall looks like the rocks in a turbulent stream after ages of wearing. The brick has been cut away in a few weeks. Coal may be destructive in its action, but it need not be. A hot stream of coal and air driven at high speed against a wall will cut it out. A low-fusing point brick is melted down; a refractory brick is cut away mechanically. It is possible to cut away carborundum brick by misdirecting a fire which did not even approach in temperature the melting temperature of the brick. But such action is u
essary. Except at the burning tuyere, brick need n
a destructive flame, and the tuyere itself can be s
that repairs will be minor and infrequent. The
for melting down is to avoid high velocity along t
work. If a wall must take the full force of a

it is best to protect it with loose brick or to pass a current of combustion air along its face, which both deflects and protects. An arch can always be treated in this way. Some of the combustion air is cut off from a burner and sent along on top and over it. The total volume of air used is not increased and a reducing fire can still be carried; the heat distribution is noticeably good.

An interesting problem in furnace construction presented itself in a case where it was desired to heat certain metals very slowly and uniformly; the furnace to be charged when cold, that is at room temperature, and brought up to 900° C. in six hours, the rate of temperature rise not to exceed 200° C. per hour at any part of this time. After reaching 900° C. the heat was to be held for the rest of the day. Perhaps this can be done with other fuels; it was very easily done with powdered coal, and there would have been no trouble in holding to a temperature increase of 20° per hour had it been required. This was true of the first hour too, which, by the way, presents the greatest difficulty.

It may be of interest to note the result of trials upon furnaces built to heat metals for forging purposes. There is no standard of comparison as there is in the case of a boiler trial, so one had to be devised. There were eleven billets, 4 in. square and about 20 in. long, weighing approximately 91 lb. each, which were to be melted down for scrap. The two furnaces selected could each heat one-half of them at a charge, five at one time and six at the next, so the hearth was covered over 50 per cent of its area and 4 in. deep. As soon as six of these billets were heated to a smart forging temperature, just short of dripping, they were hauled out and the five cold ones put in. The hot billets were dropped in a tank of cold water and kept until they were stone cold. In this way, these charges were heated alternately all day Fuel was weighed, furnace temperatures were measured, and in order to allow for the metal burned away it was weighed, at the beginning and close of the trial, to give an average. The procedure in boiler testing was followed as



Ingot Heating Furnace Using Holbeck's System of Pulverized Coal.

closely as possible, with these two differences—the furnaces were cold when started and not all the metal was heated that could have been heated. If each charge had been twice as great, the output per pound of fuel and the working efficiency would have been nearly twice as large; for only about 10 per cent of the fuel in the furnace goes toward heating the charge; one quarter of the rest goes to heat up the brickwork, and the balance goes up the chimney.

The table below gives the results of these trials. The first was upon furnace No. 4 with cold combustion air and coal dust for fuel; the second upon No. 0 furnace with hot air and coal dust; the third was with oil on No. 0 furnace.

RESULTS OF FORGE FURNACE TRIALS

	No. 4 Furnace.	No. 0 Furnace.	No. 0 Furnace.
Kind of Coal	Coal.	Coal.	Oil.
Duration of trial	60 hr.	60 hr.	60 hr.
Temperature of furnace at start	cold	cold	cold
Temperature of furnace at finish	1370° C.	1365° C.	1350° C.
Average furnace temperature	1300° C.	1301° C.	1270° C.
Time per heat, including warming up	94 min.	85 min.	98 min.
Number of heats	8	10	9
Average time of heat, neglecting first	51 min.	41 min.	44 min.
Temperature of combustion air	16° C.	334° C.	240° C.
B.t.u. per pound fuel	14,000	14,000	19,400
Total fuel, including kindling	1042 lb.	790 lb.	518 lb.
Total steel heated	4288 lb.	5015 lb.	4563 lb.
Hourly Quantities:			
Pounds of steel per hour	573	659	604
Pounds of fuel per hour	139	104	69.5
Economic results:			
Pounds of steel per pound of fuel	4.11	6.35	8.83
B.t.u. in fuel per pound of steel	3406	2203	2196

No. 4 furnace is somewhat larger in area than No. 0. The first and second trials may be compared to show the effect of preheating the air; the second and third to show the relative merits of coal and oil.

The temperature of the heated air was apparently higher in the case of the coal than in that of oil; but all of the air was preheated for oil; while primary air, or say 25 per cent of the total air, for coal, was not heated at all. In any event the same air heater and the same furnace were used in the two cases.

The heats in this class of work are unquestionably better with coal. They are noticeably brighter and softer; to express the difference as a forge smith would, coal heat is more penetrating, and in a given furnace more work can be done, and more fuel can be well burned, with coal than with oil. Columns No. 2 and 3 of the table show a 10-per cent greater output with coal than with oil. It may be noted, however, that efficiencies are virtually the same. The same thing is true in comparing coke with oil in a large oven, and in general it may be stated that efficiencies will be equal if the fuels are properly burned, and this will cover coal upon a grate too. If burning conditions are right, if fires are carefully and intelligently watched, efficiencies will be high and will be essentially equal. When fires are not understood, when conditions are wrong and results are poor, there is no use in trying to draw conclusions from a trial. The speeds of two race horses cannot be gauged by a trial when they are both half starved. If a fire beneath a boiler cannot turn 75 per cent of itself into steam—show 75 per cent efficiency—either the operator is untrained or the burning arrangements are wrong. A skillful man will obtain better than 75 per cent.

The powdered coal furnace has no ups or downs. There is no thick fire or thin fire, fresh coal or old coal to insure fluctuations. The furnace can always be kept at its best working point, and if so kept it will be heated evenly all over. Of course, a large charge of metal to be heated will by its very volume absorb heat rapidly, causing a fall in waste gas temperature and possibly a little smoke, at first.
he nature of things, but conditions quickly bring
point where the chill is not sufficient to

affect combustion. High temperatures then come again and smoke disappears. If the rate of work to be done is constant, there is no reason why high efficiency may not be uniformly maintained by proper construction and operation. The subject has been mastered to a point beyond the experimental stage. High efficiency may be confidently relied upon. The quality of the coal is not of supreme importance. Indeed, in the developments of the future the chief attraction of powdered coal may lie in high efficiencies obtainable from low-class or refractory fuels hitherto thought unavailable.

AMERICAN LOCOMOTIVE CO. PLANT

At the works of the American Locomotive Company at Schenectady, N. Y., there has been installed one of the powdered coal plants of the Quigley Furnace and Foundry Co. of Springfield, Mass. This has been visited a number of times by the author. This plant works very satisfactorily with a distinct saving in fuel charges. The plant formerly used a fuel-oil system for heating the blanks for drop-forgings and for general small forging work.

This plant was built and started in May, 1913, and while there has been the usual amount of trouble to be expected in starting up new equipment, the system is at the present time giving good results.

The coal milling and distributing plant is motor-driven and centrally located in a building of non-combustible construction. At present it has a capacity of 5 tons per hour, and it is so arranged that by duplicating the dryer and pulverizer its capacity can be doubled. The plant has a concrete hopper placed under an elevated track where it can be served with coal either by discharging directly into it from the car or from the stock pile by means of a traveling crane and grab bucket. The concrete hopper discharges into a rotary crusher capable of crushing 20 tons per hour of run-of-mine coal to $\frac{3}{4}$-in. cubes, from which the coal is carried by means of a bucket elevator to a storage bin which

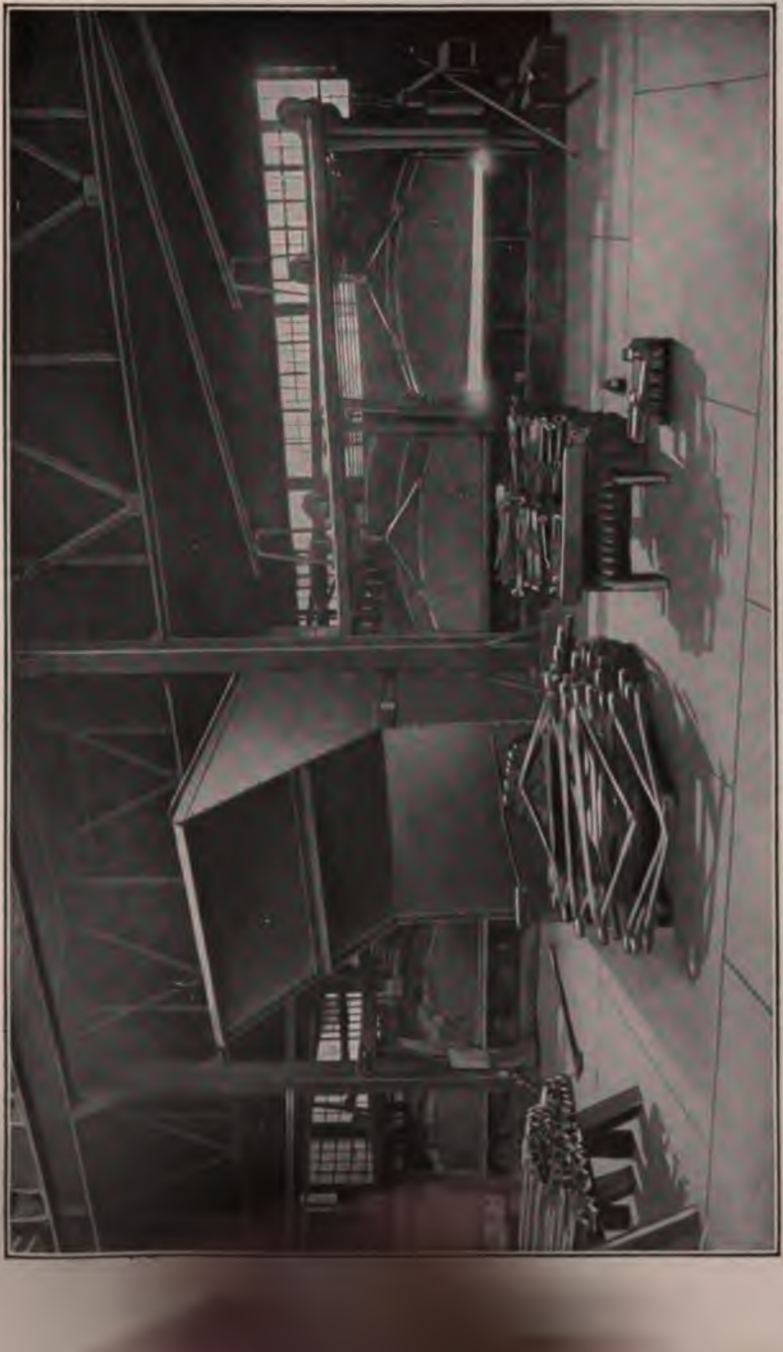


Plate-heating Furnace Arrangements.

discharges through chutes and a reciprocating feeder into an indirect dryer of 6 tons capacity per hour. From here it is elevated to a dried-coal storage bin arranged to feed by chutes directly into the pulverizer, then elevated to a pulverized-coal storage bin, from which it is distributed by means of screw conveyors to the various furnaces in the drop-forge shop. The plans permit of further extension to the blacksmith shop and other departments later.

The milling building is detached, well ventilated, and well built in conformity with underwriters' requirements, and has been accepted by them as on a par with buildings containing equipment for fuel oil or gas for industrial purposes. There has been no trouble whatever from spontaneous combustion, or from fires from other causes, and there appears to be no reason to expect trouble from this source if ordinary precautions are used, as required with any other kind of fuel.

The feed device used at the American Locomotive shops has a motor-driven controller and consists mainly of two screws, the upper located so as to propel the powdered coal from the bin forward to a point where it falls, in a stream, past an opening through which a cross current of air at low pressure (a small portion of the total amount of the air required for combustion) is directed, so as to force the desired quantity of coal to the burner through suitable pipes. The lower or return screw is of greater pitch than the upper and returns any excess of coal to the base of the hopper. By this method a continuous stream of coal passes the opening and any portion up to the capacity of the upper screw may be utilized by increasing or decreasing the force of the cross jet of air. As the lower screw has a greater capacity than the upper it is impossible to clog the device even when the consumption of coal is altogether stopped.

The oil was measured as follows: There were two tanks with gauge glasses, so that the exact level of oil could be determined: the tanks were so connected that one could be filled with oil while the other supplied oil to the furnaces.

TESTS AT AMERICAN LOCOMOTIVE COMPANY WORKS

Test on Oil Furnace.

Nov. 14, 1913. Test started 6:10 A.M.—ran to 3:35 P.M.

Furnace ran 11 heats, 12 pieces to each heat: pedestal die wedges.

Heats.	Time, Minutes.	Forging Time, Minutes.	Pieces.
1	31	18	12
2	25	18	12
3	20	16	12
4	21	19	12
5	23	18	12
6	21	17	12
7	40	22	12
8	28	16	12
9	21	16	12
10	23	17	12
11	31	16	12

Total actual time, 9 hours, 25 minutes.

Oil used, 1238 gallons.

Blast on oil burner, 6½ ounces from 6-in. pipe, reduced to 4 in. at burner.

Motor, 120 horse-power, runs three No. 10 Sturtevant blowers for blast.

Each blast consumed 1½ horse-power.

COMPARISON OF POWDERED COAL FURNACE AND OIL FURNACE

(Both same size)

	Powdered Coal Furnace.	Fuel Oil Furnace.
Time run	10 hr. 22 min.	9 hr. 25 min.
Fuel consumed	2177 lb. coal	138 gal. oil
Average time per heat	25.1 min.	25.8 min.
Average time per forging	1.87 min.	1.47 min.
Actual forgings	122	132
Forgings to be counted		132
Cost of fuel at contract [illegible]		$6.69 (4.8c. per gal.)
Cost of fuel delivered to		$6.89

The tanks were accurately calibrated and the oil consumption computed accordingly.

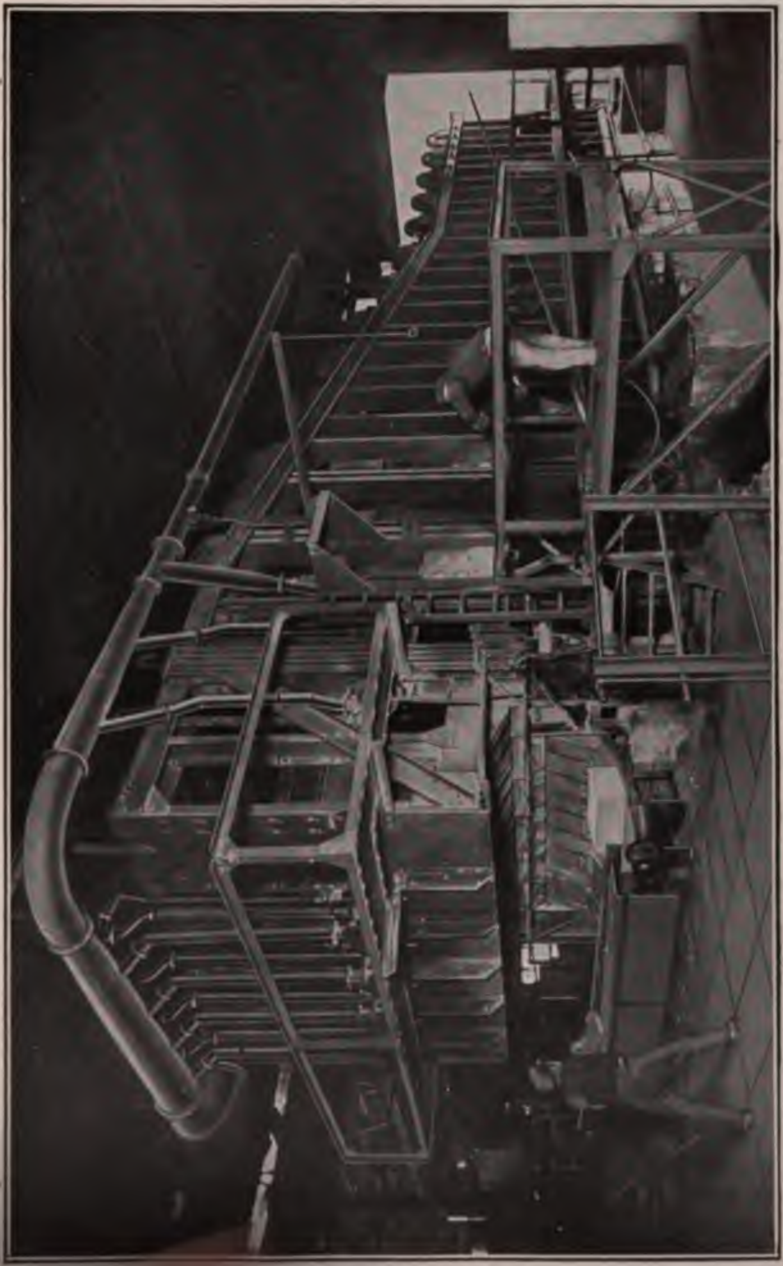
The powdered coal furnace ran fifty-seven minutes longer than the oil furnace. However, thirty minutes were lost because of failure to charge the furnace on November 12 and eighteen minutes were lost on November 13, because the plate for heating the dies was not put in at the proper time. The work was on pedestal die wedges, which are of iron. The blocks weigh 25 lb. and the forgings 16 lb. The time lost on the powdered coal furnace would have been more than sufficient for making ten additional forgings, so that the amounts turned out by the furnaces should be considered equal, as indicated in the table above.

Some weight should be given the fact that the oil costs were probably kept at a minimum, as the operator was thoroughly familiar with oil and was able to obtain the maximum heat with the minimum amount of fuel. The same men ran the two furnaces and the only variable factor of importance was that the ram used on the hammer at the oil furnace was about 500 lb. heavier than the ram on the hammer at the coal furnace. This did not affect the time of heats, but allowed a quicker forging time and there was therefore less time lost with nothing in the furnace, when using oil.

AMERICAN IRON AND STEEL PLANTS

The Lebanon plant is described by Mr. James Lord in the Western Engineer's Society Proceedings. About 1903, the American Iron and Steel Company, noting the use of powdered coal in large furnaces in the cement industry, commenced the experimental use of this fuel in metallurgical furnaces.

From the first it was apparent that economical use depended upon absolute control of the feed by the burner. This having been accomplished, the fuel has been applied to over one hundred furnaces of various types, such as those for puddling and heating, and of smaller sizes for reheating nut, bolt and spike bars.



Continuous Billet Heating Furnace using Holbeck System.

It has proved to be a commercial success for all of the above purposes and can probably be used with equal economy for basic open-hearth steel furnaces, either with or without checker work. Experience in the use of this fuel over a number of years has been so satisfactory and so economical that the company is now largely increasing its installation, and is about to apply it to open-hearth furnaces.

They have found that success in using powdered coal for metallurgical furnaces requires:

1. That both the free and combined moisture be expelled by artificial heat, down to about 0.5 per cent.

2. That the coal be pulverized so that 95 per cent will pass through a 100-mesh sieve, and over 80 per cent will pass through a 200-mesh sieve.

3. That delivery to the furnace be controlled by the burner so that the proper feed may be secured. The capacities of burners used at Lebanon range from 40 lb. per hour to 900 lb.

In the puddling and heating furnaces, the firing grates formerly used for lump coal serve as combustion chambers for the powdered coal, and collect a large portion of the ash. The combustion chambers in the heating furnaces hold about 6 tons of iron piles, and are about 5 ft. from back to bridge wall. Some ash is collected at the base of the stack, and some, of impalpable fineness, passes through the stack. That which falls upon the material in the furnace is too small a percentage to affect it unfavorably. In one of the plants, located near a residential section, suction fans have been installed to collect the ash.

The equipment for preparation of the powdered coal at the Lebanon plant is as follows:

The slack coal is conveyed automatically from the car to the pile, then taken by screw conveyors to the dryers, and in the same manner from the dryers to the pulverizers. When ready for use it is similarly conveyed throughout the works, in some cases as much as a third of a mile. It is not touched by hand or shovel from the freight car to the furnace

Using slack coal, a crusher is unnecessary. Various types of dryers are used. The pulverizers are of two types, the horizontal tube mill, and the upright grinding mill. They are practically equal in efficiency, each machine delivering 4 to 4½ tons per hour. Both of these types of mill are made by a number of manufacturers.

As the coal leaves the pulverizing plant it is weighed on a large automatic scale. The heating and puddling furnaces have each a small automatic scale, and the total of the small scales is checked up each day with the large scale.

At the end of each line there should be an overflow pipe to prevent the coal from choking up the screw, if anything should happen to the cross lines. Otherwise, should the coal overflow near an open fire, it will at once ignite.

Attached to each of the furnaces is a tank or hopper, of size to carry about a fifteen-hours' supply of powdered coal. On several occasions the fuel has ignited in these tanks, usually on Monday mornings when the left-over coal had accumulated moisture. In such cases, it is only necessary to stop the supply and feed the burning coal into the furnace until the tank is empty. There is no danger of an explosion under these conditions. Indeed, during the entire experience at the Lebanon works with this fuel there have been no explosions. These occur from coal in suspension in a room in contact with flame. The same result would follow filling a room with wheat flour in suspension. Proper attention to the pulverizing plant and machinery will eliminate this possible danger.

The fuel should be delivered to the puddling and heating furnaces at a low air pressure. This plant employs 4 to 6 oz. of blast to blow the coal through a small pipe from the burner inlet to the large blast pipe, which in a heating furnace is from 10 to 14 in. in diameter. This large pipe conveys the coal
to the furnace at [redacted] oz. or less per square inch.
If these roof and side walls of a
furnace be [illegible] lling mill will last four
or five m [illegible] , six days per week.

As to the economy of the fuel, actual results in the Central works during the months of April and May, 1913, are as follows:

Puddling Furnaces. The following figures show the quantity of fuel consumed to produce a ton of puddled bar, made from gray forge pig iron. (The product during these months was high-grade bar requiring special work and time.)

	April, Lb.	May, Lb.
No. 23 furnace	1362	1318
No. 24 furnace	1109	1277
No. 25 furnace	1271	1472
No. 26 furnace	1371	1362

The average during the same months on a lower grade of pig and cast scrap was 1239 lb.

Heating Furnaces. In heating piles for rolling the following results were obtained during the same months:

Name of Mill.	April, Lb.	May, Lb.
12-inch Central	516	528
12-inch West	544	570
16-inch Central	519	533

The figures show the weight of fuel in pounds, consumed to produce a gross ton of rolled bars. On steel billets the amount would be one-third less.

Records for the year 1912 show the cost of preparing pulverized coal to have been as follows:

	Rate of Gross ton of Coal Powdered
Fuel for dryer	$0.034
Repairs to buildings	0.002
Operation	0.145
Power (steam and electric)	0.221
Repairs to machinery and equipment	0.200
Total	$0.602

Rivet Heating Furnaces using Holbeck System.

This total includes the cost of transmission through pipes to the furnaces.

The item of repairs includes expenses which should have been charged over the past eight years, and the total cost of preparation and transmission did not actually exceed 50 cents per ton of powdered coal produced during 1912.

If the cost of transmission is separated from that of actual preparation, the cost of the latter would be less than 40 cents. Many plants would not need the expensive transmission system required at Lebanon.

In general, so many variable quantities enter into the matter of cost that one can hardly set an exact figure. At the same time, it is certainly useless to accept the low figures given by manufacturers of pulverizing machines. We hear much about costs of 10 or 12 cents per ton for grinding, which may be adequate for some part of the process. What the purchaser wishes to know is the total cost of handling the coal from the cars up to the furnace. The very extensive and well-designed plant at Lebanon, from exact figures, counts on 50 cents per ton for unloading, screening, drying, grinding and placing at the furnace. This includes the wages of two men engaged all the time in unloading cars and caring for the distribution of the coal. It also includes the care of the dryer, care of the grinding plants and upkeep of the apparatus. This 50 cents a ton is just about taken care of by the difference between the cost of slack coal and that of run-of-mine coal, the latter of which could be used on ordinary grate fires.

When the coal is prepared as herein outlined, smoke is practically eliminated. If the stack shows black smoke, it proves that there is wasteful use of the fuel, to the detriment of the operator's interest, and this is or should be at once corrected.

Fig. 45 shows the outline of a furnace from which gas samples and furnace temperatures were taken at the three points indicated. Gases were analyzed by an Orsat apparatus and furnace temperatures were taken by a Thwing radiation pyrometer. The first three runs were made under working conditions, heating a pipe pile, and the last three with the furnace empty. The coal used contained 54.86 per cent fixed carbon, 1.85 per cent sulphur, 0.74 per cent moisture, 32.68 per cent volatile matter and 11.72 per cent ash. Its computed heat value was 13,250 B.t.u. per pound. It was ground so that 89.07 per cent passed over a 100-mesh and 70.82 per cent over a 200-mesh screen.

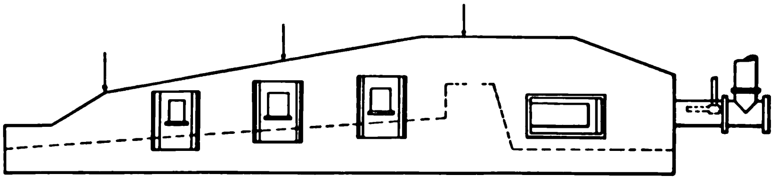


FIG. 45.—Outline of Lebanon Furnace.

Test. No.	Date.	Time.	Gas Analysis.									Speed of Control Screw R.p.m.	Air Blast Pressure.		Air Blast Temp. Deg. Fahr.
			Bridge.			Center.			Near Neck.				Primary Blast. (Oz.)	Secondary Blast. (Oz.)	
			CO_2	O	CO	CO_2	O	CO	CO_2	O	CO				
1	10/14/14	11:15 A.M.	11.4	3.6	0	15.0	2.1	0	12.0	2.8	0				
2		2:55 P.M.	11.0	6.0	0	9.0	0.7	0	15.0	1.7	0				
3		4:30 P.M.	13.4	2.6	0	12.0	4.0	0	13.6	4.6	0				
4	10/15/14	4:10 P.M.	13.4	2.8	0	13.0	3.0	0	12.8	3.2	0	54–62	5.625	0.625	428
5		4:50 P.M.	11.4	3.6	0	12.2	2.8	0	9.2	3.2	5	37–42	5.625	0.500	
6		5:25 P.M.	8 6	5.4	0	9.0	4.0	0	9.0	4.6	0	37–42	5.625	0.500	

STACK AND FURNACE CONDITIONS

Test No.	Bridge.			Center.			Near Neck.		Temp. Deg. F.
	Smoke from Stack.	Furnace.	Temp. Deg. F.	Smoke from Stack.	Furnace.	Temp. Deg. F.	Smoke from Stack.	Furnace.	
1	None	Ready to Draw	2560	Trace	Beginning to Drawing		None	Drawing	
2	None	Drawing	......	None	Drawing	......	[illegible]	Making Bottom [illegible]	
3	Trace	Ready to Draw	......	None	Ready to Draw				
4	Trace	Empty	2420	None	Empty	[illegible]			2300
5	None	Empty	2420	None	Empty	[illegible]			2350
6	None	Empty	2530	None	Empty	[illegible]			2540

CHAPTER VIII

POWDERED COAL UNDER BOILERS

A PLANT in New Jersey recently visited by the author made a test on crushed coal, ground to a fineness of only about 60 mesh. The coal was fed into a " coal integrator " and conveyed to the boiler furnace, a distance of approximately 100 ft., by air at 4 lb. pressure, through a 1½-in. rubber hose. The test started at 11 A.M. with the furnace empty, the steam gauge then showing 80 lb., and at 11:17 A.M. the gauge was at 123 lb. and the safety valve blew. The amount of coal burned during this time was 470 lb. and the amount of water evaporated about 9.5 barrels of 400 lb. each. Then $(400 \times 9.5) \div 470 = 8.08$ lb. of water were evaporated per pound of coal. During the test the coal was fed through the top of the furnace, while the air for combustion, at 1-oz. pressure, was fed into the furnace from both sides at the rate of 180 cu.ft. of air per pound of coal. The heat was so concentrated and intense that the inside lining of the fire box door was melted. Ash piled up in the furnace, necessitating a shut-down after running about an hour, for cleaning out. The trouble was no doubt due to insufficient grinding.

Reference was made in Chapter IV to the apparatus devised by Whelpley and Storer, for firing a boiler in part with powdered coal. This was experimented with at an early date by Chief Engineer B. F. Isherwood, U.S.N. The boiler was of the horizontal type with two flues, having 299 sq.ft. of heating surface and 13½ sq.ft. of grate. A coal fire was maintained upon the grate and the powdered coal fed in above it, a fire arch being used to maintain the furnace temperature when the powdered coal was used, but not when the grate fire was employed alone.

Figs. 47 to 49 show an arrangement of apparatus for burning powdered coal under a Heine boiler. Most of those engaged in experimental work on powdered coal under boilers have ignored the fact that a combustion chamber for burning powdered coal must be considerably larger than one for burning the same quantity of coal upon a grate. The floor of the combustion chamber in this instance consists of cinders thrown upon a row of water-tubes *A*. There is a wide slot in the middle of this floor, through which the liquid ash may drop into the ash pit, which is water-cooled. The globules of liquid ash take on a skin or shell in falling, which prevents the formation of a lake at the bott[illegible] of the ash pit.

The com[illegible] chamber shou

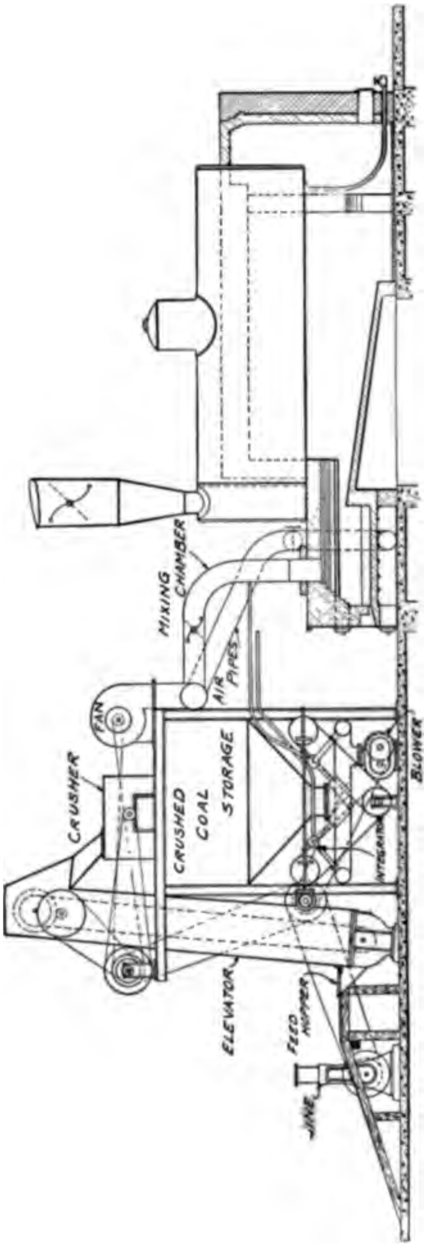
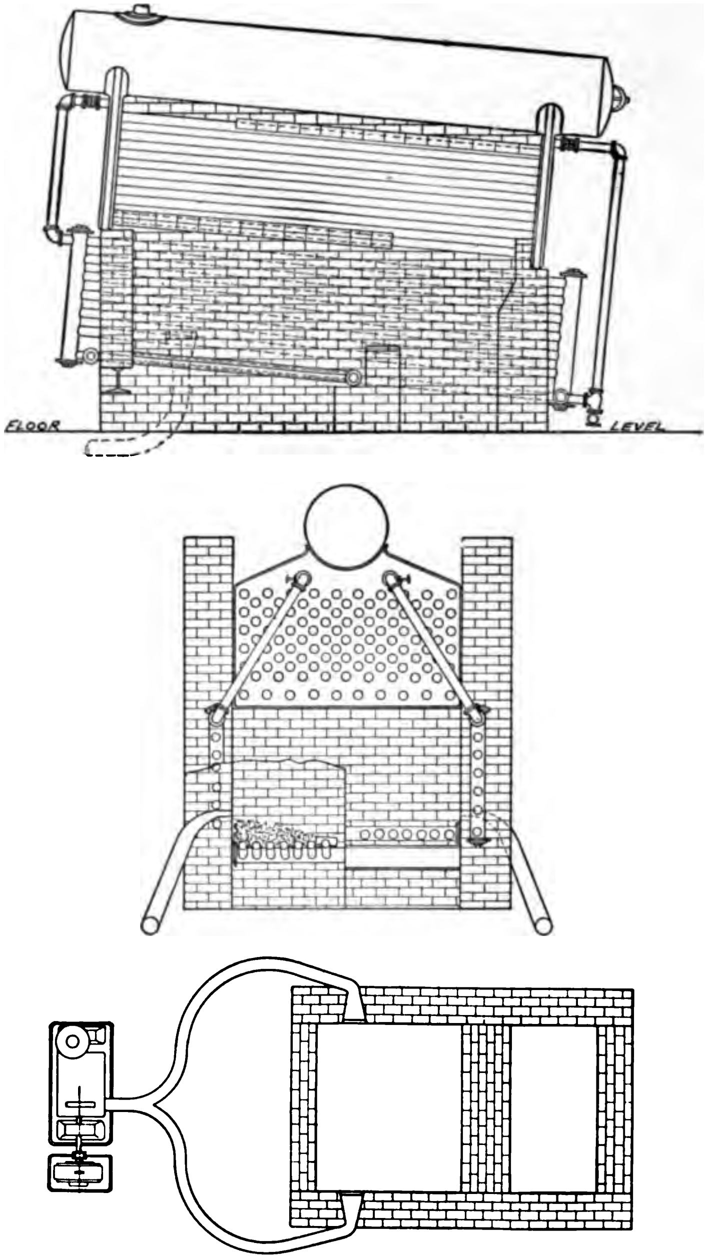


Fig. 46.—Plant Using Coarsely Ground Coal under Steam Boiler.



Figs. 47, 48 and 49.—Heine Boilers Arranged for Pulverized Coal.

a volume of about 1 cu.ft. for each 3 lb. of coal burned per hour.

In Fig. 48, *B* are water-tubes which protect the furnace walls from smelting; *C* is the bed of ashes, or floor of the combustion chamber, *D* is the slot through which the liquid ash may drip, *E* are the headers and *F* are the tuyeres.

The ash pit should be 3 ft. deep to allow the liquid ash to cool while falling. All joints should be protected from the direct action of the flames.

At the 1914 spring meeting of the A.S.M.E., Mr. F. R. Low presented a paper entitled " Pulverized Coal for Steam-Making " which described the following forms of apparatus used for powdered coal.

There have been three general types of apparatus produced: Fig. 50 shows the Pinther, in which the powdered coal is emptied into a hopper above a feed-co mechanism and is then carried into a furnace by draft; the second type is that having a mechani

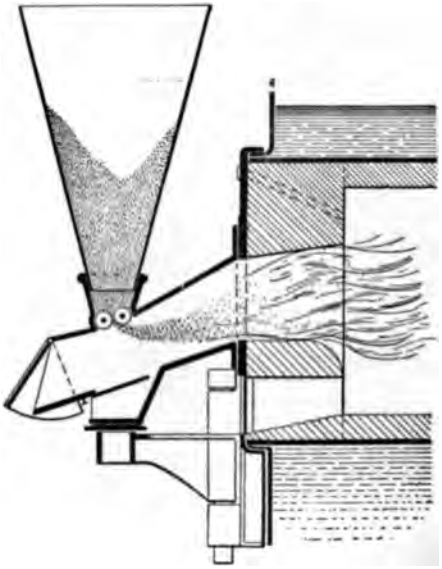


FIG. 50.—Pinther Apparatus.

like the revolving brush of the Schwartzkopf apparatus, Fig. 51; and the third form is that in which the coal is blown into the furnace, as in the Day or Ideal apparatus.

With the first type, boiler efficiencies of from 75 to 80 per cent were obtained, but the capacity was limited. When sufficient draft was applied to introduce a considerable amount of coal, the velocity was such as to carry unconsumed particles of coal into the back connection and tubes. When fuel was introduced into the powdered fuel furnace at a rate which gave the full rated capacity of the boiler, a particle remained in the combustion zone of an ordinary furnace less than half a second.

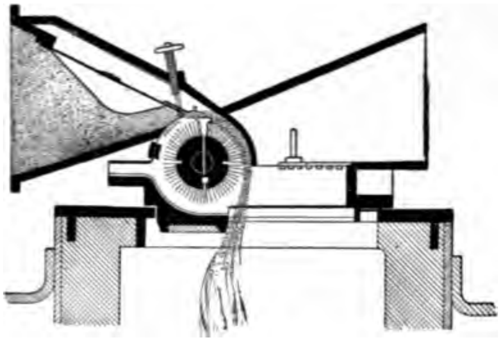


FIG. 51.—Schwartzkopf Apparatus.

In 1910, Mr. J. E. Blake installed under a 300-horsepower water-tube boiler at the Henry Phipps power plant the arrangement shown in Fig. 52. The pulverizer served as its own blower, sending the powdered coal, mixed with air, to the furnace; where, in this installation, it was introduced by a series of nozzles extending across the width of the furnace. A little less than the rated horse power of the boiler was obtained, with an efficiency of about 79 per cent.

A later form of the Blake apparatus was installed in the winter of 1913 at the Peter Doelger brewery in New York. The powdered coal was delivered into the top of an exten-

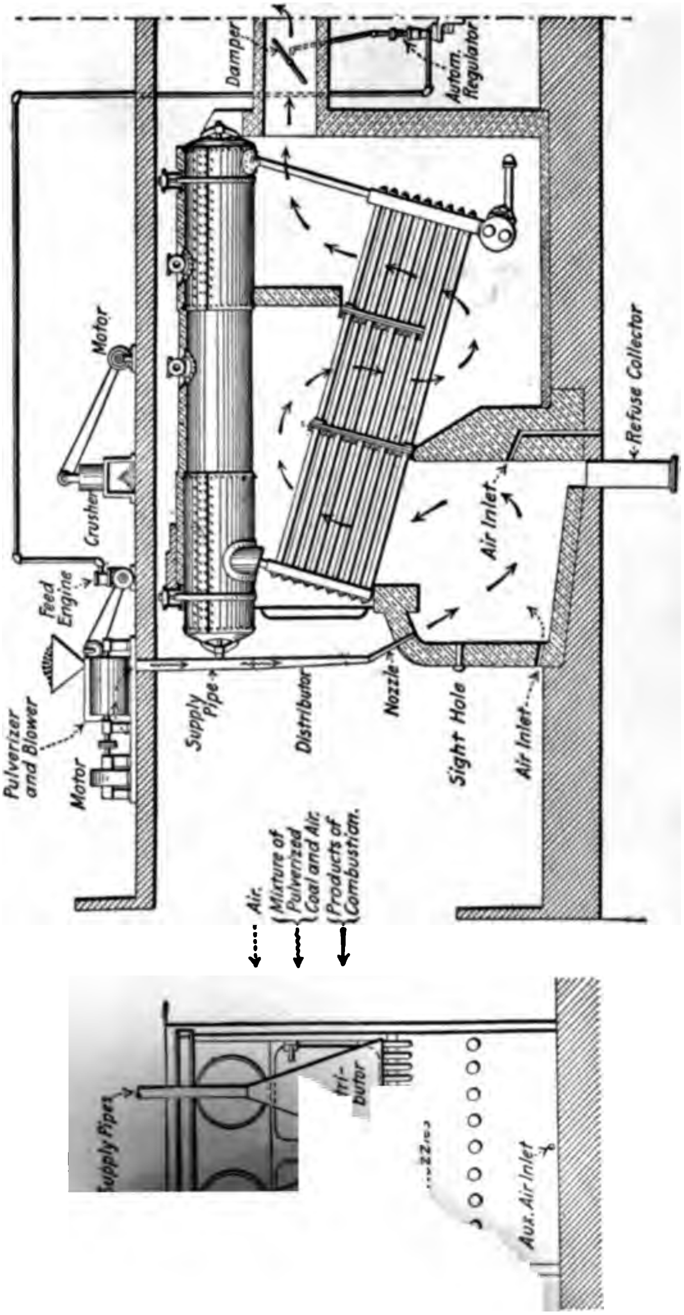


FIG. 52.—Blake-Phipps Apparatus.

sion furnace or " Dutch oven." Smokeless combustion and high efficiency were obtained, the principal trouble being from slag, which accumulated on the roof and side of the furnace and piled up in such masses upon the floor that frequent shut-downs were required for its removal. As much water was evaporated with 1000 lb. of the powdered coal as had formerly been evaporated with 1400 lb. of ordinary coal, but the cost of furnace maintenance, the frequent laying-off of the boiler for the removal of slag, and the cost of pulverizing, counteracted this advantage and the system was abandoned after a trial of about eight weeks.

Mr. Claude Bettingdon of Johannesburg, South Africa (located in a section where the price of coal is high), attacked the problem by designing a boiler especially for use with powdered coal. He took out his first patent in the United States, but the boiler was first commercially exploited in England. In this boiler, the feed is upward, as shown in Fig. 53, through a water-jacketed nozzle in the center of a vertical furnace. The pulverizer acts as a blower, and the air supply is preheated. From the pulverizer the coal passes to a separator, where the larger particles settle out and return again to be treated, the finer passing on as coal in suspension. As a particle has to pass twice the length of the furnace (upward and downward) to escape, there is no difficulty in obtaining complete combustion.

The inner row of tubes of the circular furnace are covered with a special refractory covering to within a short distance of the bottom header, making a brick-lined combustion chamber. Special bricks are placed loosely around the tubes, but they soon become coated with molten ash and slag, which weld them into a solid wall and close the crevices between the lining and the top header. The ash which is not so slagged to the furnace surfaces, or carried out by the draft, drips into the ash pit below the lower header. The destructive effect of an impinging flame upon the brickwork is avoided by receiving the flame upon the lower head of the central drum, or upon the accumulation of gas in

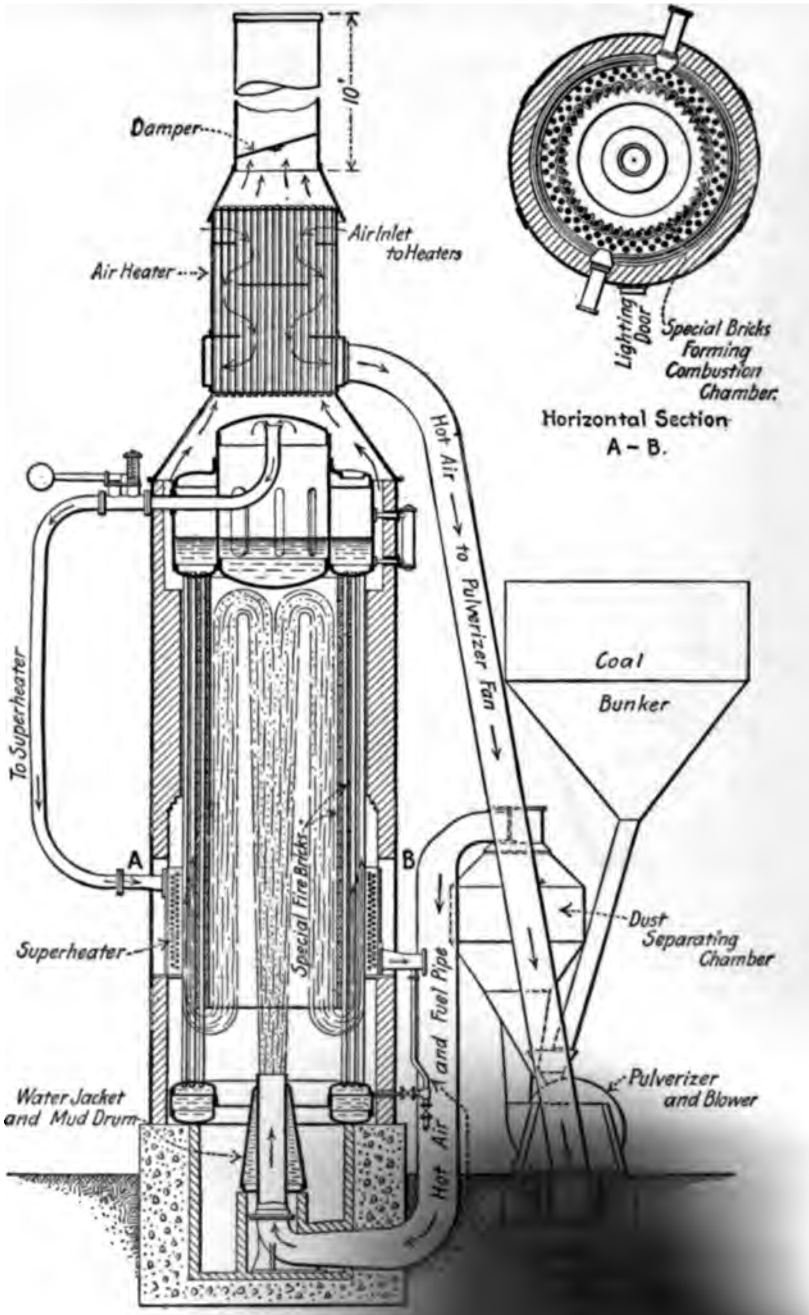


Fig. 53.—Bettington [illegible]

the upper end of the chamber. The region of greatest heat intensity is in the core, while the tubes and shell are subjected to the lesser temperatures of the somewhat cooled gases, which have not yet passed away. The radiant heat is very effective upon tubes and shell, and the metal surfaces must be kept perfectly clean. Particular care must be taken as to the water level. One of these boilers having 2606 sq.ft. of heating surface has been running for over four years at the works of the builders. It evaporates regularly 14,000 lb. and has been worked up to 22,000 lb. of water per hour. These rates, however (5.4 and 8.4 lb. per square foot of heating surface) are attained with stoker-fired boilers using ordinary coal.

A contributor to *Power* who has had two of these boilers in charge says that the steel head of the upper drum burned through at one time, probably because dirt collected upon it; and that in spite of the cooling effect of the tubes the special bricks forming the furnace quickly burn away, and frequent renewals are necessary. Care must be taken lest the lining burn through and the gas be short-circuited. Although this boiler will burn low-grade coals successfully, and while under steam is easily managed, one fireman being able to look after several boilers, these advantages are largely offset, in his opinion, by high cleaning and maintenance charges.

The makers say their experience has been that a lining will last about two years, and that even large holes will automatically seal up. The parts which require most frequent renewals are the beaters and liners of the pulverizer. These are of manganese steel, and can be replaced in about two hours. The makers claim an approximate life for the beaters corresponding with 1500, and for the liners with 2000 tons of coal handled. A user, after ten months of experience, says that the set of blades runs from 1000 to 1200 hours. The use of heated air in the pulverizer allows coal having 15 per cent or more of moisture to be handled successfully; a separate heater or dryer is recommended with large boilers. The makers allow 2 to 3 per cent of the boiler capacity for pulverizing. There has been some trouble from leaky water jackets, putting the flame out, but this has been overcome by the use of welded jackets. The CO_2 is carried at about 15 per cent in regular practice. The possibility of getting an adequate supply of oxygen to the finely comminuted carbon facilitates perfect and smokeless combustion with a minimum air supply, but with the rates of combustion demanded in present practice the result is often an excessively high temperature with erosive and reducing characteristics which, however good they may be for metallurgical purposes, are not favorable to the longevity of a boiler furnace. If this temperature is kept down by feeding less fuel, the capacity is limited, while if it is kept down by using an excess of air the economic advantage just cited is sacrificed.

Boiler at Works of the General Electric Company. Mr. A. S. Mann has described in the General Electric Review

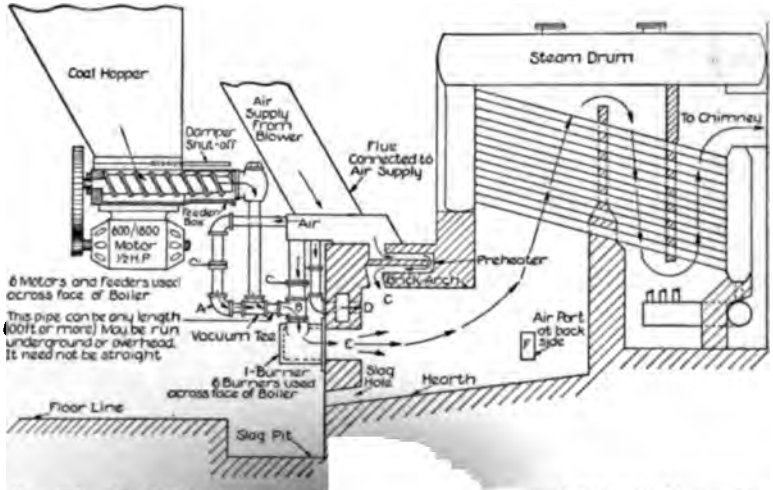

Coal Hopper
Damper Shut-off
Air Supply From Blower
Flue Connected to Air Supply
Steam Drum
To Chimney
Feeder Box
Air
600/1800 Motor 1/2 H.P
6 Motors and Feeders used across face of Boiler
This pipe can be any length (100ft or more) May be run underground or overhead. It need not be straight
A
B
Vacuum Tee
D
C
E
Preheater
Brick Arch
Air Port at back side
F
1-Burner 6 Burners used across face of Boiler
Slag Hole
Hearth
Floor Line
Slag Pit

FIG. 54.—B. & W. Boiler for P eral Electric Company.

some intere powdered coal under a b ace to burn coal dust. It was a single 474 horse-power (10 sq.ft. rating) unit that had formerly been fitted with an extension front, making a 4-ft. Dutch oven, for burning oil. He used the same oven and the same front for the coal furnace, but

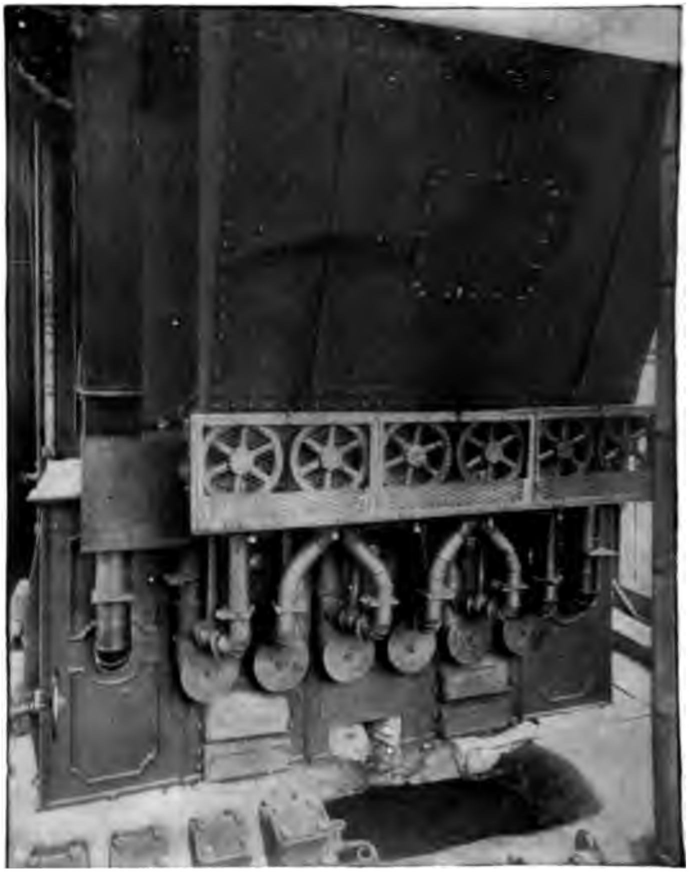


FIG. 55. Powdered Coal in B. & W. Boiler.

the internal arrangements were altered. Fig. 54 shows a longitudinal section of this furnace, Fig. 55 is a photograph of the front, and Fig. 56 is a diagram of the front.

The same feeders and the same driving gear are us those shown in Figs. 34 and 40. In order to perf mixture and to supply both air and coal in small quantities six burners and six feeders were used. Air is admitted at six separate ports; that is, each particle of coal encounters six air currents before it passes on to the heating surface; and every air current is pointed across, or at an angle with, the burning current, thus making the stirring action perfect. In consequence, combustion is virtually complete in 8 ft. of travel even when carrying 200 per cent of normal load. Five hundred and twenty pounds per front foot of furnace have been burned with only 7 ft. between header and floor line. The boiler has carried 265 per cent load long enough to show that such loads are possible, and 220 per cent or more can be carried indefinitely, for there are no cleaning periods.

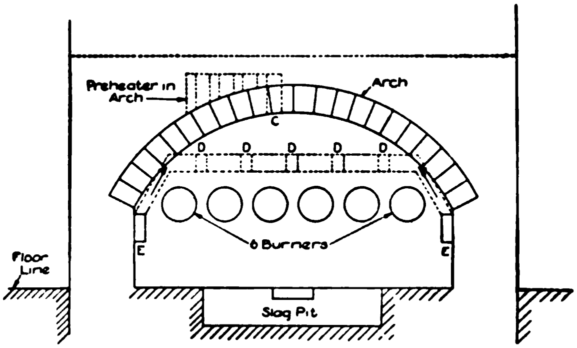


Fig. 56.—Front of Boiler.—General Electric Co.

The six burners across the furnace front are so arranged that the air currents issuing from them revolve in counter directions with respect to each pair. The diagram of Fig. 57 shows this relationship. The air currents act like a train of toothed gears at the tuyere mouth and so tend to preserve a path of travel normal to the general gas current. These swirling masses proceed a little way only, when they meet with air from the [illegible] ports. Fig. 58 shows this m[illegible] ard in a corkscrew path, [illegible] result is the curve *D*.

The whole volume follows this path and can be plainly seen at light loads making its turn beneath the arch. There are six curves like *D*, one for each burner, and each curve

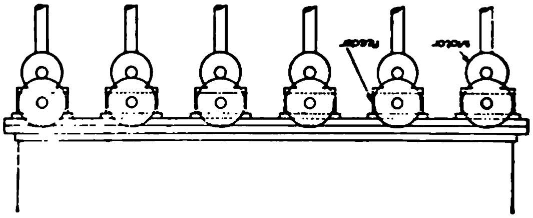


FIG. 57.—Arrangement of Burners.—B. & W. Boiler.

is a corkscrew at least part way. The side wall currents help to prolong the mixing action.

One difficulty presents itself in burning powdered coal that is not met in burning coal by the usual processes. Powdered coal is burned in suspension, and as it travels at 40 or 50 ft. per second it must be consumed in one-sixth

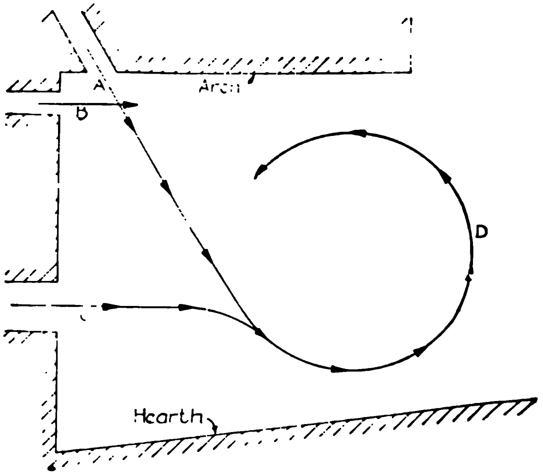


FIG. 58.—Air Currents in Boiler Furnace.

second or so. If it is not, it will not be completely oxidized. During this brief time interval there is only one-fifth pound burning in this boiler, even at heaviest loads.

instant is there a greater quantity of coal than this in the furnace. With a grate, no coal particle need burn in a short time, the average time for all particles being half an hour, for there is a ton and a half or so on the grate, burning slowly. This apparent disability really works to the advantage of powdered coal.

For starting a first fire beneath this boiler, an armful of kindling was placed at the mouth of one burner and lighted; then secondary air was admitted at this burner, followed by primary air. A switch started a motor and its feeder, sending down coal; and with a puff of smoke the fire was going. The next burner caught from the first and so two more, making four in all, were set at work. The memorandum taken at the time was:

8:26 A.M., light fire, four burners ½ on;
8:33 A.M., 10 lb. pressure;
8:46 A.M., 140 lb. pressure.

At 8:46 A.M. the fireman checked his coal feed and went up overhead to open the stop valve, and in two more minutes the boiler was carrying its load.

This fire was started in a new cold furnace beneath a boiler full of cold water. With half the coal-burning capacity in use, pressure was up in twenty minutes.

The first boiler trial gave 68 per cent efficiency with 131 per cent of normal load. Efficiencies were calculated by dividing the heat in the steam by the heat in the coal (laboratory test) that produced it. That is, if there were realized 10 lb. of equivalent evaporation per pound of coal and the coal contained 14,000 B.t.u., the efficiency was (10 × 966) ÷ 14,000 = 0.69. Successive trials gave the results shown in the table below:

RESULTS OF BOILER TRIALS

	1	2	3	4	5	6	7	8	9	10	11
[illegible] per cent....	131	186	212	119	97	136	154	154	141	164	205
[illegible], per cent	68	63.8	65.8	68	71.8	65.5	71	69.4	66.1	63.7	75.7
[illegible] lb. coal	210	178	150	190	250	181	200	226	216	168	208
[illegible]ure..	559	684	786	583	568	652	693	685	628	678	724

Since the last and best trial the boiler has given as good or better efficiencies for a week at a time, including coal for all purposes, and using railroad weights for coal, the fire being put out at 5 P.M. and kindled fresh at 7:30 A.M. every day.

The earlier experiments showed nothing remarkable in economy, but in the beginning it was not known how much air to use or where best to admit it. After experiment No. 5, observations began to coördinate. Nos. 7 and 8 were instructive, but some mistakes were made before reaching No. 11, and this was not final. Better work can be done with less air, though perhaps there are many fires not giving 75.7 per cent efficiency at 205 per cent load.

Mr. Mann experimented in a comprehensive way with air dampers, noting air volumes, flue temperatures and color of smoke. Each air supply had its damper, and these were adjusted independently. With a given coal feed if it was found that changing the points of application of air permitted a reduction in air volume, with an accompanying rise in flue temperature and with no smoke, it was concluded that an improvement was being made.

In this way it was found best to admit as little air at *A* and *B* as possible, a great deal at *C*, some at *D*, and a little at *E* (*F* is used only on heaviest loads, that is above 210 per cent). In general it may be stated that, as the air supply departs from 200 cu.ft. per pound of coal, efficiency falls.

The operator is supplied with gauges which gave him the heights of water column corresponding with definite air volumes. Each gauge is marked with its corresponding number of coal notches on feeder rheostats. The fireman thus makes the water column fix his coal feed. Dampers are marked and results are definite.

It is to be observed that in measuring air the volume is much better than measuring the CO_2 in chimney gases. Two hundred feet of air gives CO_2 of about 15.3 per cent; 208 ft. gives 14.7 per cent; and this small change (which no CO_2 apparatus can be sure of) gives a marked change in evaporation. The same change in air volume makes the water column move ¼ in. Furthermore, the fireman knows of any change instantly. He measures it and he measures *all* of the air: while the CO_2 content is judged from a minute sample and is half an hour behind the time.

It will pay so to arrange the air piping on any boiler that air volumes can be measured instantly, and this is true whether a chimney or a fan produces the draft. A nozzle plug is used in the pipe, though perhaps a Pitot tube might do; however, the nozzle plug acts well and it is liked. If a fireman sees his water column go up he knows that a hole is coming in his fire and he knows it right away. This knowledge is of more value to him than any other information of the sort he could have.

Boiler trials already made point the way to improvement. There is enough heat in the flue gases to warrant the placing of heating surface in its path. Everything in the shape of tar has been burned out of the fuel, and it is planned to put about 600 ft. of 1¼-in. tubing in the breeching and send feed water through it. The stack is clear. All soot drops in the gas chambers long before reaching the stack, so that all troubles commonly met with on this account are absent. More trials will be conducted when this addition is ready.

Other losses are not great. Radiation from the furnace is small, for the furnace is virtually surrounded with air passages, and heat that gets into them is returned to the furnace. These air passages, and the deflecting air currents, *C*, *D*, *E*, and *F*, do much toward protecting the furnace walls. One arch has been burned out. It melted down from 9
to 4 in., when it fell, but it has stood up nearly six m
It did not run every day with heavy load and d
nights at all; but it was made of common fire b
are not intended for high temperatures. The n
better material, the bricks costing $37.00 pe
It may pay to use carborundum.

As to how much it costs to fire boilers with p that depends upon how much is made. Coal has to be crushed, elevated, dried and distributed, whatever burning system is used. There are two elevations and the additional pulverizing for powdered coal. The question of real interest is, how much more does it cost to prepare and burn coal than by the usual process. In this plant, the pulverizer is small, and the first cost with motor installed was about $1000 per ton pulverized per day. If it were to run only five hours a day, leaving ample time for repairs, fixed charges would amount to about 7 cents per ton, allowing 10 per cent per year.

Electric current costs, in cents per ton, are as follows: Driving dryer, 1.95; two elevations, 0.77; pulverizing, 14.8; which makes 17.52 cents per short ton for current and 24.52 cents total cost including fixed charges. This total is reduced by about one-third with large pulverizers.

The pulverizer calls for some attention, but it is in the coal house with other machinery and whatever labor it needs is more than made up in decreased labor of firing. The blower at the furnace gives a pressure of 3 oz., which is ample, so that 25 cents additional per ton is all that can be charged against pulverized coal. The plant has not run long enough to say what the cost of repairs will be, but two years of experience have shown that it is nominal, or at least no greater than is met with in all coal-handling machinery.

Figs. 59 and 60 show the plan of a powdered coal plant which the Fuller Engineering Company have recently installed for the Missouri, Kansas & Texas Railroad, at Parsons, Kansas. This plant will, when completed, contain ten 250 horse-power Heine boilers; although at the present time only eight boilers are installed.

Fig. 61 gives a cross-section through the boiler setting and shows just how the powdered coal is handled into the combustion chambers.

The engineers of this plant made the following replies to questions submitted by the author:

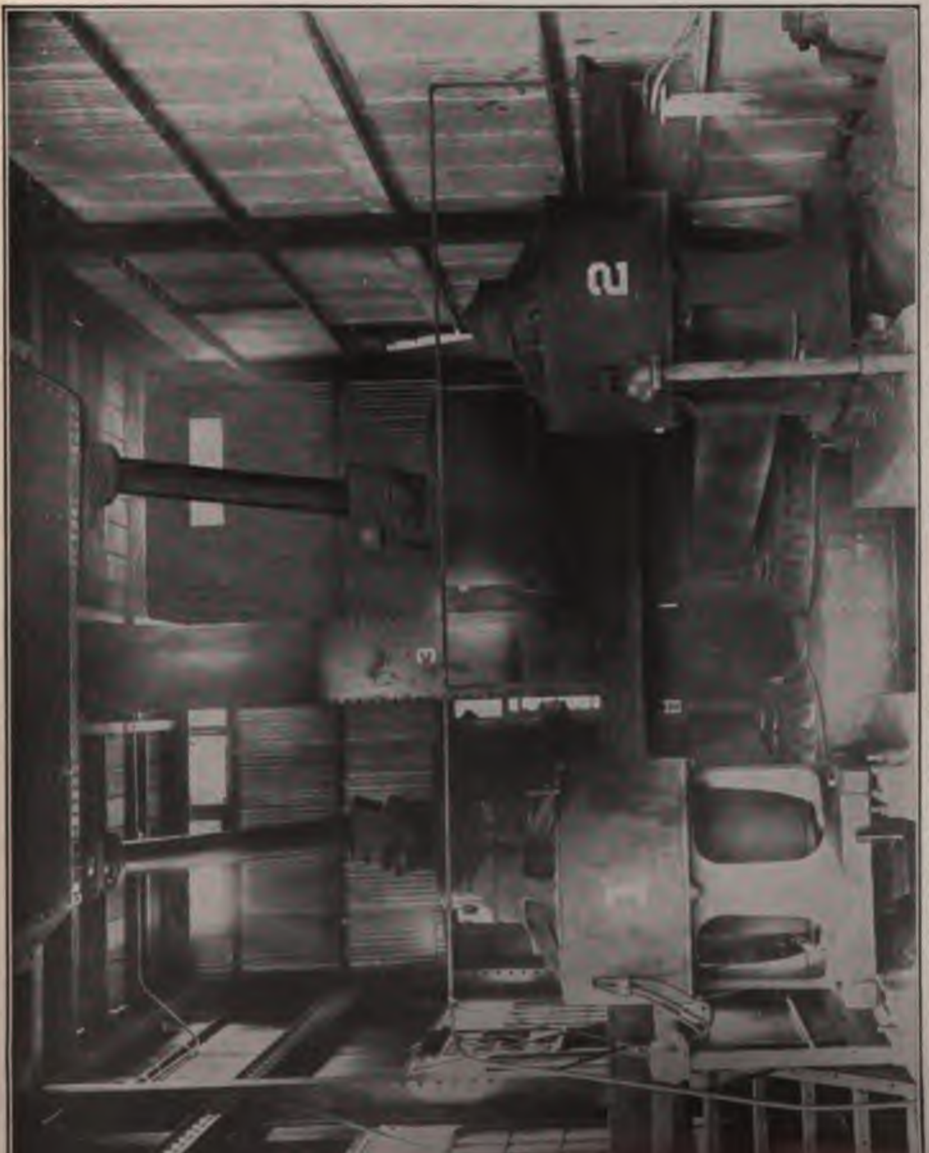


FIG. 59.—M. K. & T. R. R. Plant, Parsons, Kas.—Fuller Engineering Co.

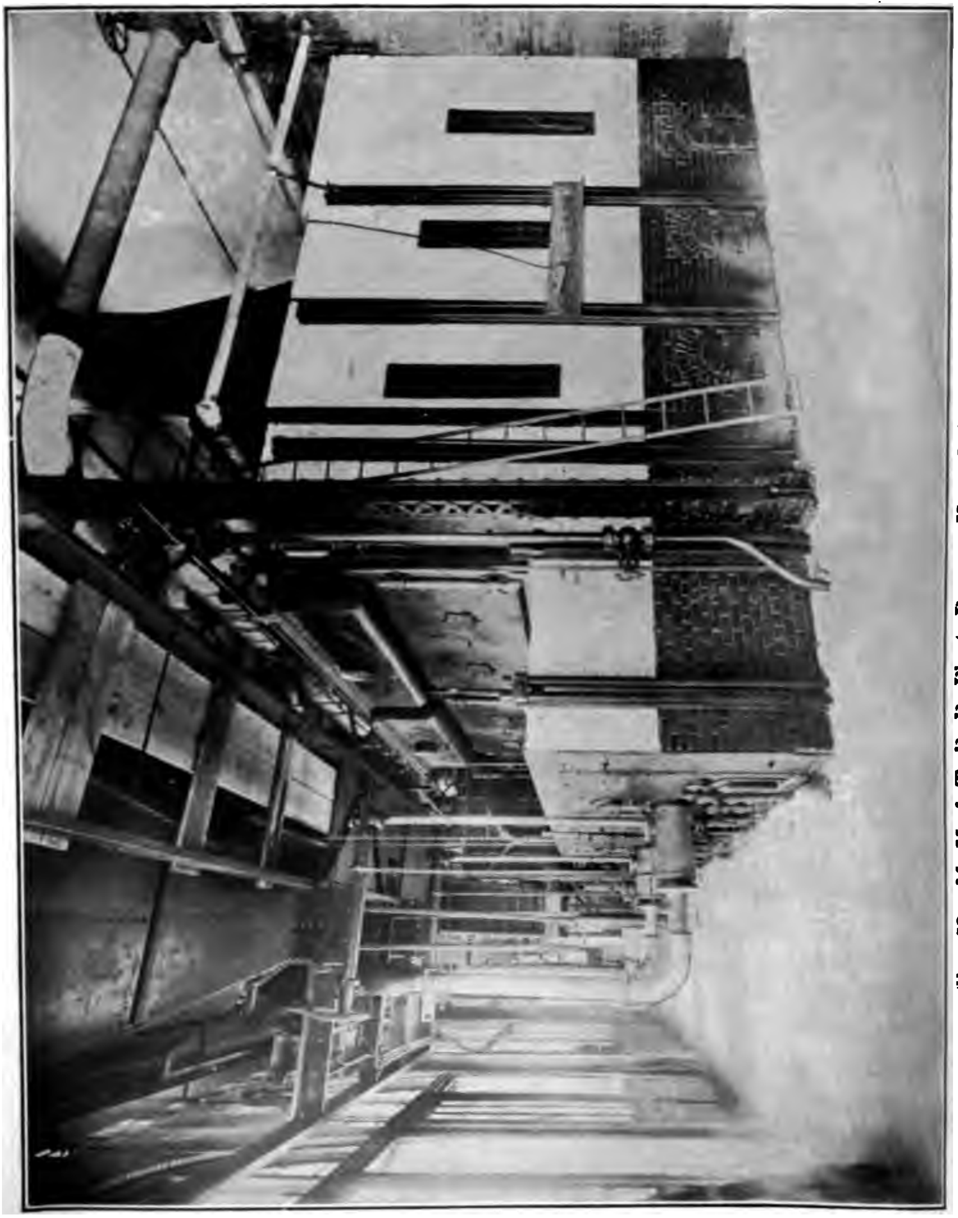


FIG. 60.—M. K. & T. R. R. Plant, Parsons, Kas.—Fuller Engineering Co.

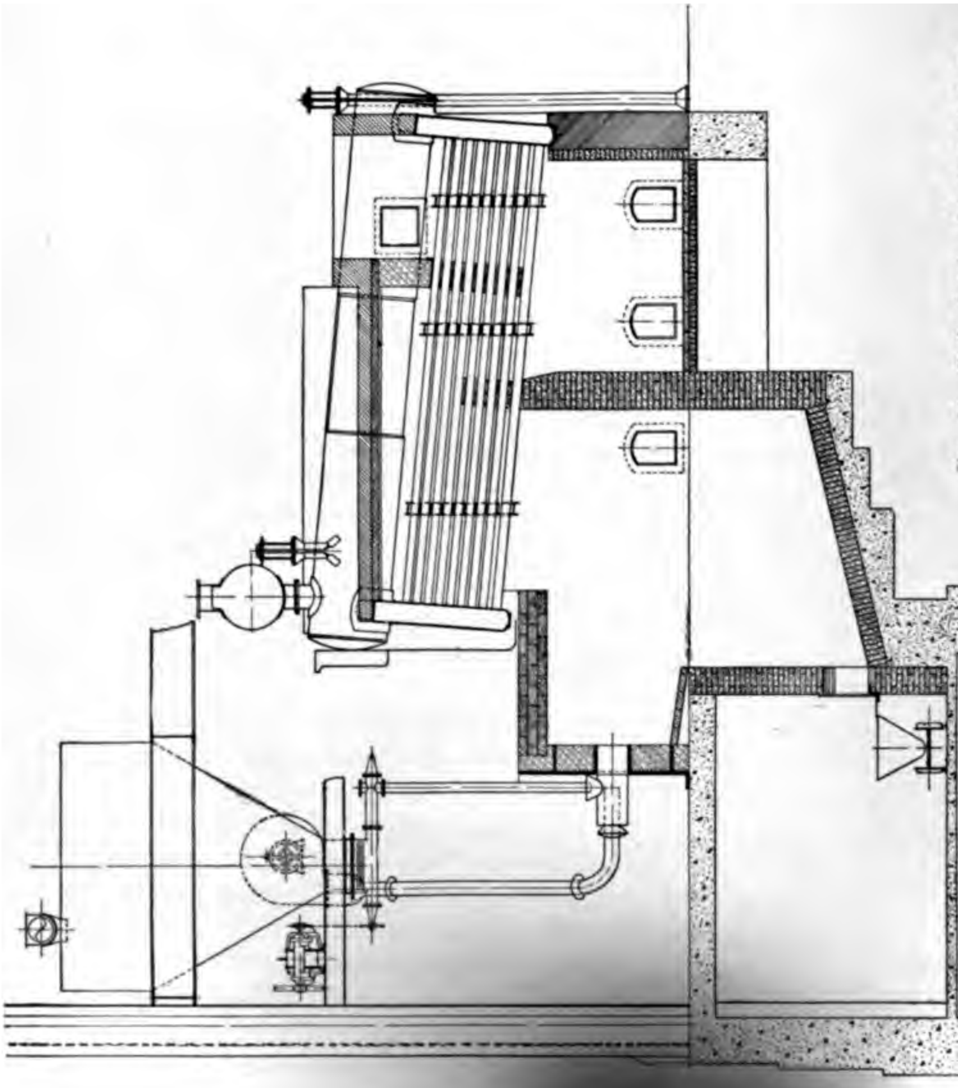


FIG. 61.—Boiler Setting, M. K. & T. R. R.

1. The amount of coal burned per horse power depends strictly upon the quality of coal burned. It is safe to assume that a boiler efficiency of not less than 75 per cent can readily be obtained with powdered coal as a fuel. In our practice we base our calculations on using 1293 heat units per pound of water from and at 212°. The equivalent evaporation obtained per pound of coal burned should equal the heat value of the coal used divided by 1293.

2. The steam pressure will be 150 lb., and with feed water at a temperature of 200° the factor of evaporation will be 1.0584.

3. As to feed control, there will be located directly below, and attached to, the powdered coal storage bin, a feed-screw operating inside of a bored cast pipe with very little clearance (to prevent the coal from rushing around the screw or passing the screw when in operation). The feed-screw is driven by means of a motor, driving directly to a speed regulator, and then through the speed regulator to the feed screw. Air supply for carrying the coal into the furnace and for combustion will be furnished by a fan driven by a direct-connected motor. There will be one fan for each two boilers. There are gates located in each blast pipe leading to the combustion chambers, and also a regulating cone for varying the effective area between the blast pipe and the outside pipe, at the entrance point in the front wall of combustion chamber. The regulating cone controls the percentage of excess air induced. By means of the equipment outlined, positive control of the amount of coal as well as of the amount of air supplied will be attained and also the pressure of air admitted to the furnace will be under control.

4. The fireman will be governed in making adjustments by conditions and by the demand for steam. With proper apparatus at hand, he will be able to regulate the supply at all times. Firemen having had some experience with powdered coal burning should be able to judge by the appearance of the furnace whether prop

obtained.

5. With the furnace properly designed and proportioned to the quantity of coal to be burned, no serious effects will occur because of flame impingement against the bridge wall. Furnaces for burning powdered coal are to-day designed so that excessive velocities are eliminated. High velocities cause destructive conditions.

6. It is not expected that the conveyor screw will break with properly designed feeding mechanism, but an extra screw should be on hand. Slides are located between the feeder and the bin proper; so that should any accident occur requiring the insertion of a new feed-screw, this can readily be done. The bin capacity is designed to suit operating conditions. A ten-hours' supply can easily be stored in bins in front of the boilers, and more if desired. The design of the bins, however, should be such that when coal is being fed from the bottom the majority of the coal is in motion.

7. With coal properly prepared and pulverized and burned in a properly designed furnace, 75 to 80 per cent of the ash will deposit in the combustion chamber, the balance of the ash being so fine after the carbon is burned out that it is carried away as a light haze.

8. The coal will not cake in the bin in a properly managed plant, or in one which has suitable equipment. The drying apparatus is sufficiently large to take care of the maximum powdered coal demand.

9. There are 38 lb. of powdered coal to a cubic foot.

10. So far as we know the boilers will be intermittently fired, operating full during the day and at about one-quarter capacity at night.

11. We have raised steam in a 400-horse-power Rust boiler with cold setting, and with feed water at 180°, in forty-five to fifty-five minutes, to 150 lb. gauge pressure. However, this practice not good as it forces the setting somewhat and is likely use trouble with the furnace walls.

burning powdered coal under
ce since March, 1915, at

the works of the American Locomotive Co., Schenectady, N. Y. Some data on this plant are given by Mr. C. L. Heisler in the Journal of the A.S.M.E. for December, 1916. The percentage of CO_2, by a recording chart checked by the Orsat apparatus, is rarely under 16 and is oftener above 17. The boiler is one of a battery of Franklin water-tube boilers, the rest of which employ mechanical stokers. It was fitted with a deep hopper-shaped furnace extending the whole length of the boiler and tapering down to a slag pit at the bottom, without vertical walls or arches. The coal enters the front end at an angle of about 45° with the vertical. The 9-in. front sloping furnace wall is supported by a row of scrap boiler tubes. The lower row of water tubes is shielded at the rear half of its length by the ordinary tiling of a Heine setting.

Coal is fed by a screw feeder from a hopper into the air blast at a point about 3 ft. away from the furnace tuyeres. Three tuyeres are used, consisting of wrought-iron pipe nipples, 10 by 24 in. The air blast pressure is from ½ to 1½ oz., atmospheric pressure is maintained in the furnace, and there is a slight suction inward at the slag hole at the base of the furnace.

The sloping side walls of the furnace are coated with 1 to 3 in. of slag and are in perfect condition. No trouble is experienced from coke or cinders clogging the spaces between the water tubes. Repairs have been trifling. Evaporative tests have shown a materially higher efficiency than could be obtained from a duplicate boiler with ordinary coal fired by mechanical stokers, and a much quicker response is made to sudden demands for steam. An ordinary fireroom helper was able to give the furnace all the attention required.

CHAPTER IX

POWDERED COAL FOR LOCOMOTIVES

MR. J. E. MUHLFELD, in a paper read before the New York Railroad Club at its February, 1916, meeting, and in a subsequent paper presented to the A.S.M.E. at its meeting of December, 1916, has presented data on the application of powdered coal to locomotives from which the following is largely abstracted.

The present annual consumption of powdered coal in the United States is over 8,000,000 tons. The general use of this fuel in industrial kilns and furnaces has demonstrated its effectiveness and economy.

The expenditure for locomotive fuel (which the Interstate Commerce Commission reports as $249,507,624, or about 23 per cent of the transportation expenses of 242,657 operated miles of steam railway in the United States, for the fiscal year ending June 30, 1915) is, next to labor, the largest single item of cost in steam railway operation.

The necessity for conserving the limited supply of oil in the rapidly exhausting fields for other than locomotive purposes will shortly eliminate it from railway motive power use.

The large quantity of steam used by the modern locomotive necessitates high rates of evaporation, and these can be economically obtained only by some means for burning solid fuel other than on grates; in order to reduce the waste due to the loss of combustible dust and that from imperfect combustion.

Steam locomotives must be equipped to approximate more nearly the electric locomotive, with regard to the limination of smoke, soot, cinders and sparks; the reduction ise, time for dispatching at terminals, and stand-by losses; and the increasing of the daily mileage by longer runs and more nearly continuous service between general repair periods.

Workmen of a higher average quality should be induced to enter the service as firemen, eligible for promotion as engineers, by reducing the arduous work now required to shovel ahead and supply coarse coal to grates, and to rake and clean fires and ash-pans.

The future steam locomotive will be required to produce maximum hauling capacity per unit of total weight, at the minimum cost per pound of draw-bar pull, and with the least liability to delay because of mechanical failures.

In meeting the conditions outlined above, powdered coal has succeeded because of the following advantages:

1. It offers opportunity for even greater accomplishments in the steam railway field than have heretofore been obtained through its use in cement kilns and in metallurgical furnaces.

2. It produces a saving of from 15 to 25 per cent in coal of equivalent heat value, as compared with hand firing of coarse coal on grates. Powdered coal may run as high as 10 per cent in sulphur and 35 per cent in ash and still produce maximum steam-heating capacity; so that otherwise unsuitable and unsalable or refuse grades of coal may be utilized, and hence the saving in cost per unit of heat evolved will be a considerable item.

3. It enables us to maintain fire-box temperatures and sustained boiler capacities equivalent to and exceeding those obtainable from crude or fuel oil.

4. It maintains the steam locomotive on its present relatively low first cost and expense-for-fixed-charge basis, and further reduces the cost for maintenance and operation of large units.

5. It eliminates the waste products of combustion and fire hazards, and permits the enlargement of exhaust steam passages and thus produces increased efficiency at the cylinders.

Commencing with Richard Trevithick's locomotive, which was built in 1803, and was the first actually to perform transportation service, general practice has been to burn wood, coal and other solid fuels in locomotive fire-boxes, on grates.

During the early development stages this method provided adequate means for utilizing the relatively high grade available fuel effectively and economically, as the rate of combustion per square foot of grate surface per hour were relatively low. But, during the past twenty-five years, continued increases in locomotive tractive force have so increased required rates of combustion that the quantity of fuel used per unit of work performed is far beyond what may be realized by more effective means now available.

While great progress has been made in the superheating and use of steam, the principal improvements that have been perfected in steam generation have been through enlarged heating surfaces better circulation of water, regulation of air admission and the use of fire-brick arches.

Early Use of Powdered Coal. The Manhattan Railroad in New York City conducted experiments with the use of coal dust in one of their locomotives about fifteen years ago. The pulverizing of the fuel and the discharge of the coal and air into the fire-box were accomplished through the use of a combined pulverizer, blower and steam turbine located on the locomotive. In this case the cylinder exhaust was not used to produce boiler draft; the coal dust was relatively coarse; and no provision was made for precipitating and cooling the furnace slag; all of which factors no doubt contributed to the failure of the experiment.

The Swedish Government Railways have also done some experimental work in the burning of peat and coal powder in small steam locomotives during the past few years, the fuel being prepared before supplying it to the locomotive tender. In this case the powder was blown into the furnace by steam and the fire-box brick work was very complicated.

Various other experimental efforts have been made by railways in the United States and elsewhere, but, so far as is known, they have not until recently resulted in regular train operation.

The first steam railway locomotive of any considerable size to be fitted up in the United States or Canada (or, so far as is known, in the world) with a successful self-contained equipment for the burning of powdered coal in suspension was a ten-wheel type engine on the New York Central Railroad. This locomotive has 22 by 26-in. cylinders; 69-in. diameter drivers; 200-lb. boiler pressure; 55 sq.ft. of grate surface; is equipped with Schmidt superheater and a Walschaerts valve gear; has 31,000 lb. tractive power and was first converted into a powdered coal burner in the early part of 1914.

Since the development of that application similar installations have been made on a Chicago & Northwestern Railway Atlantic type locomotive, and also on a new consolidation type of locomotive recently built for the Delaware & Hudson Company. This latter locomotive is probably the largest of its type in the world. It has 63-in. diameter drivers and about 63,000 lb. of tractive force, having been designed for combination fast and tonnage freight service.

This latest effort toward the burning of powdered coal in steam locomotives has now passed the experimental stage, and arrangements have been made for proceeding with commercial applications as rapidly as the equipment can be produced.

Any solid fuel which in a dry, pulverized form will have two-thirds of its contents combustible, is suitable for steam-generating purposes.

The generally recognized waste, unsalable and otherwise low-value coal mine and strip-pit products, such as dust, sweepings, culm, slack and screenings, as well as lignite and peat, are suitable as are the larger sizes and [illegible] grades, for drying and pulverizing with a view [illegible] steam-generating purposes.

Reference to Figs. 62 and 63 will convey a general idea of the equipment found essential for the burning of powdered coal in a steam locomotive. The particular factors that have been kept in mind in the development of this apparatus have been:

1. To produce equipment that will be readily applicable to either new or existing steam locomotives of standard design.

2. To simplify and standardize the various details and make them interchangeable for the different types and sizes of locomotives.

3. To apply all possible operating equipment, in a self contained manner, to the tender fuel tank; eliminating complicated mechanism for conveying fuel from the tender to the engine, and removing from the cab all [illegible] apparatus [illegible] and air [illegible]

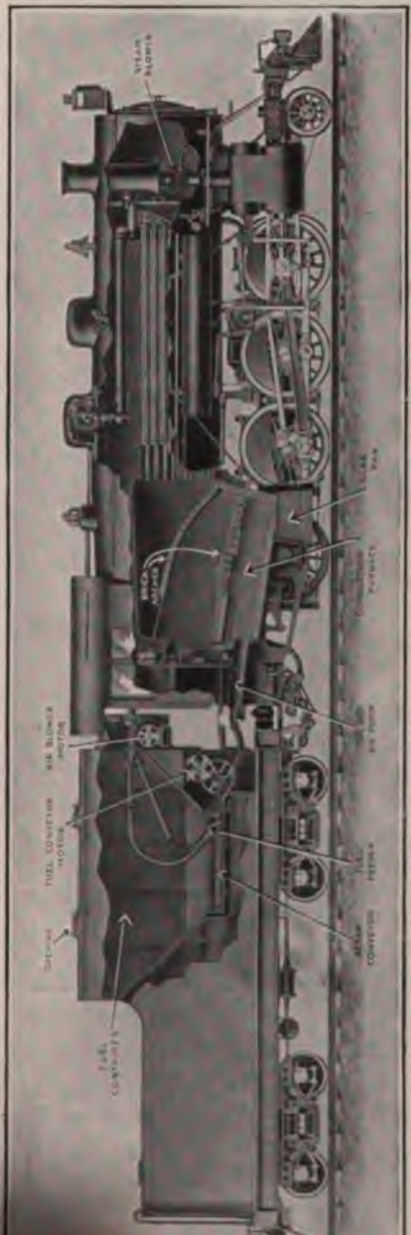


FIG. 62.—Locomotive Equipped for Powdered Coal.

4. To eliminate the necessity for any manual handling of fuel, fire or ashes in the operation.

5. To insure positive control over the fuel feed, in order to meet quickly all conditions of road or terminal operation, and to provide for quick firing-up, free steaming, good combustion, regularity of boiler pressure, uniform fire-box

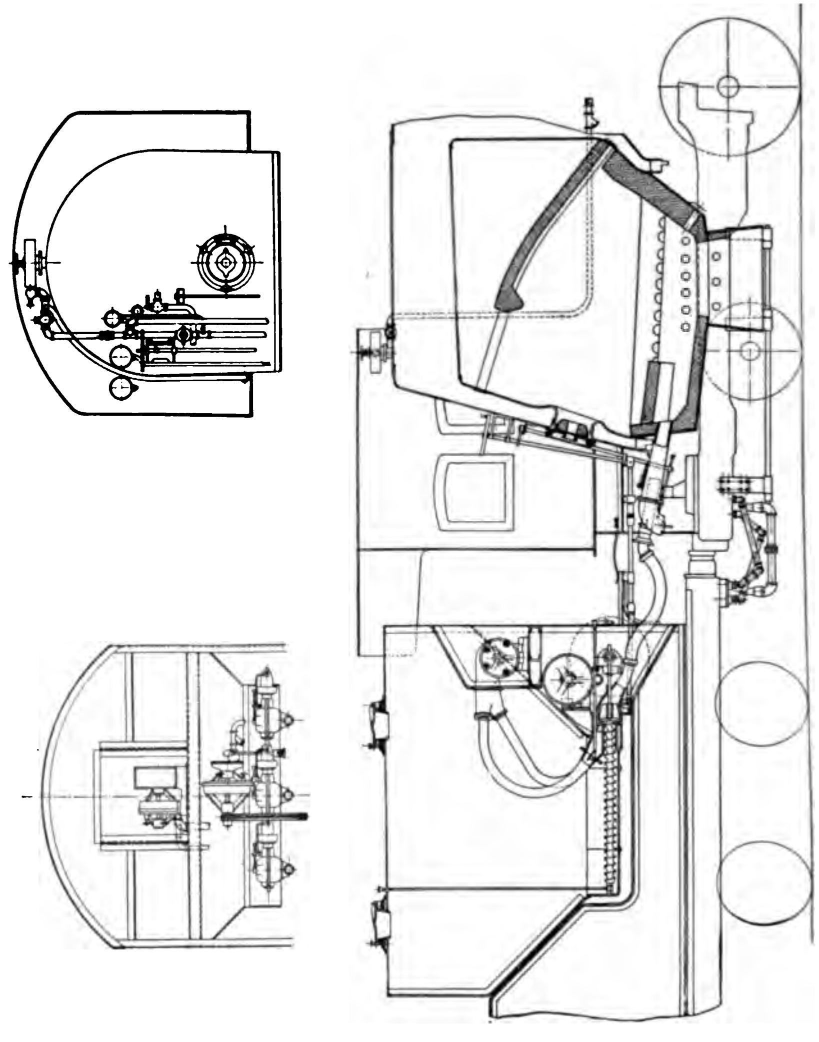


FIG. 63.—Powdered Coal Equipment in a Steam Locomotive.

temperature, and maximum capacity of boiler, with the minimum heat loss.

6. To place the entire regulation of combustion under three hand-control levers in the cab; i.e., fuel feed, air supply, and induced draft (the last employed when the locomotive is not using steam).

7. To provide a type of refractory furnace that will insure ready accessibility to all parts of the fire box for inspection and maintenance.

8. To insure a supply of dry fuel under all conditions of weather.

9. To eliminate the necessity for firing tools, such as scoops, rakes, hoes, slash-bars and grate shakers, as well as to obviate the glare, heat effect, and lowering of fire-box temperature and draft from the opening of the furnace door.

10. To minimize the noise and dust in the cab.

11. To reduce necessary engine-house facilities and delays, and expenses incident to building, preparing, cleaning and dumping fires and hostlering locomotives.

12. To make the powdered coal burning and storage equipment on the engine and tender readily convertible for the use of fuel oil.

In the application of powdered coal burning equipment to existing types of steam locomotives, the following constitute all the changes that are necessary:

Smoke Box. Remove the existing diaphragm, table and deflector plates, nettings, hand holes and cinder hoppers, enlarge the exhaust nozzle opening.

Fire Box. Remove the existing grates, ash pans, fire doors and operating gear; utilize the usual arch tubes and sectional type of brick arch; and install fire-brick-lined fire pan, primary arch, fuel and air mixers and nozzle.

Cab. Install regulating levers for furnace door, fuel and air supply.

Tender. Install enclosed fuel container equipment with fuel and pressure air conveying, feeding, [illegible] and discharge apparatus, and steam turbine [illegible] [illegible]

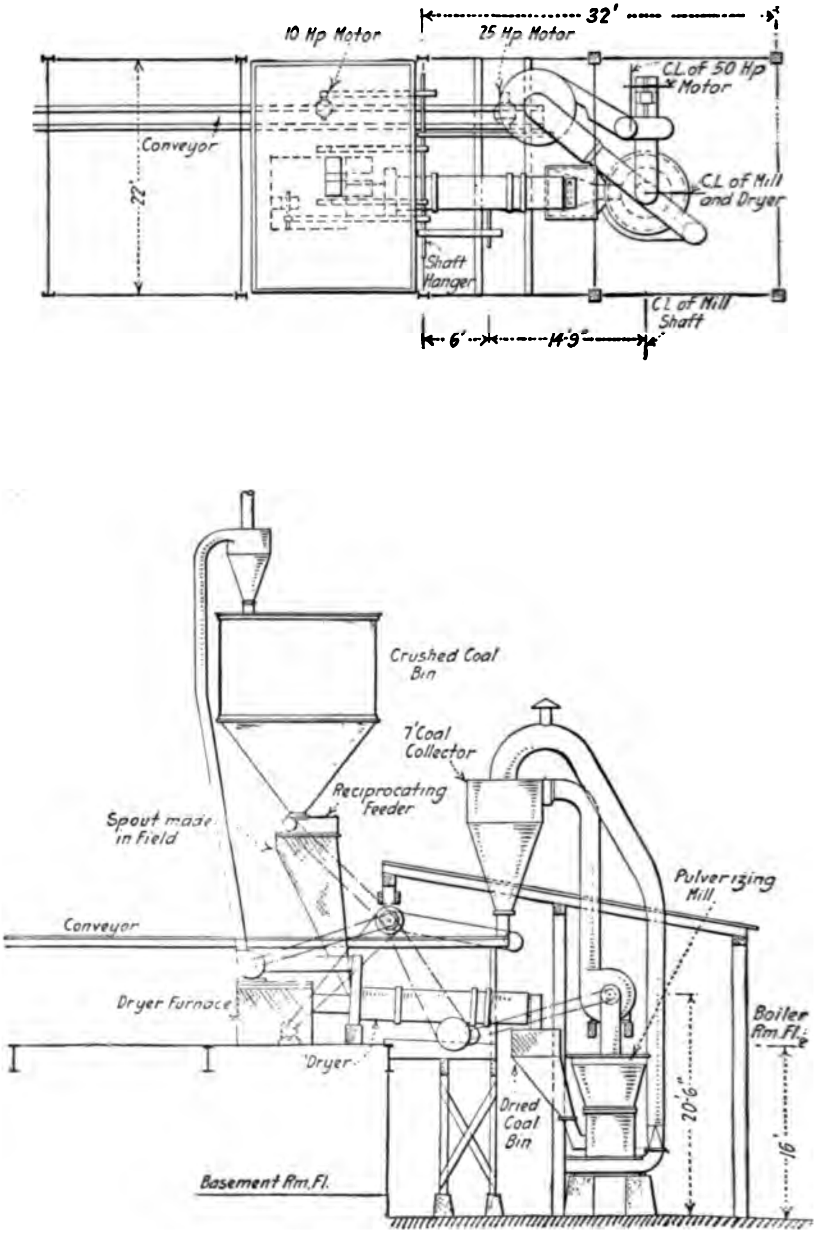


FIG. 64—Single-unit Gravity Milling Plant, Hudson Coal Co. Capacity 2 Tons per Hour

Engine and Tender Connections. These are made by the use of one or more sections of hose, which connect the fuel and pressure air outlets on the tender, with the fuel and pressure air nozzles on the engine. Metallic flexible conduits are employed for conveying the fan blast and fuel-feeding motive power.

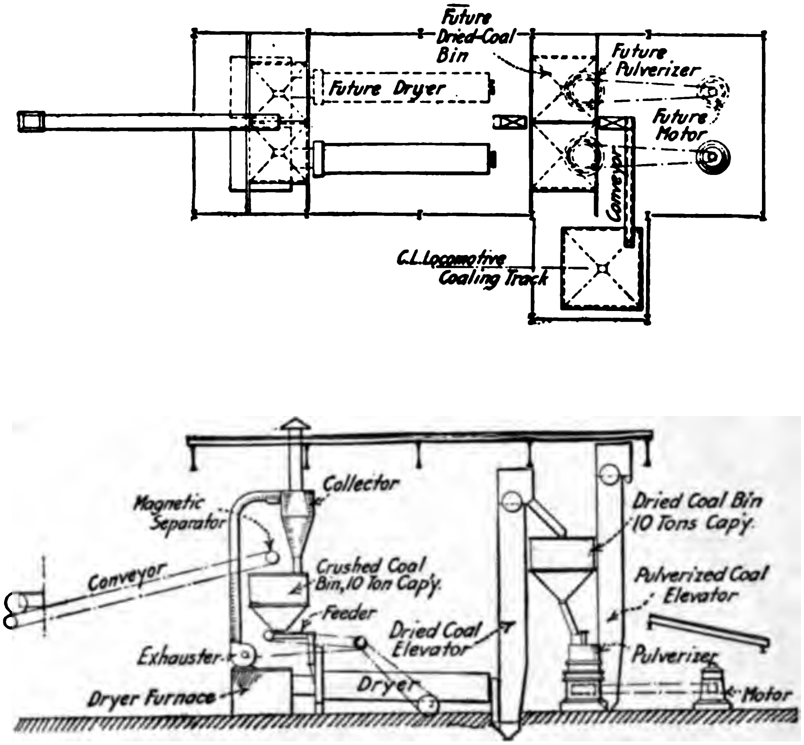


FIG. 65.—Double-unit Plant and Single-bin Locomotive Coaling Station. Capacity 8 Tons per Hour.

Operation. For firing up a locomotive, the usual steam blower is turned on in the stack, a piece of lighted waste is then passed through the fire-box door opening and placed on the furnace floor, just ahead of the [illegible] arch, after which the pressure fan and one each of [illegible] pressure air feeders are started.

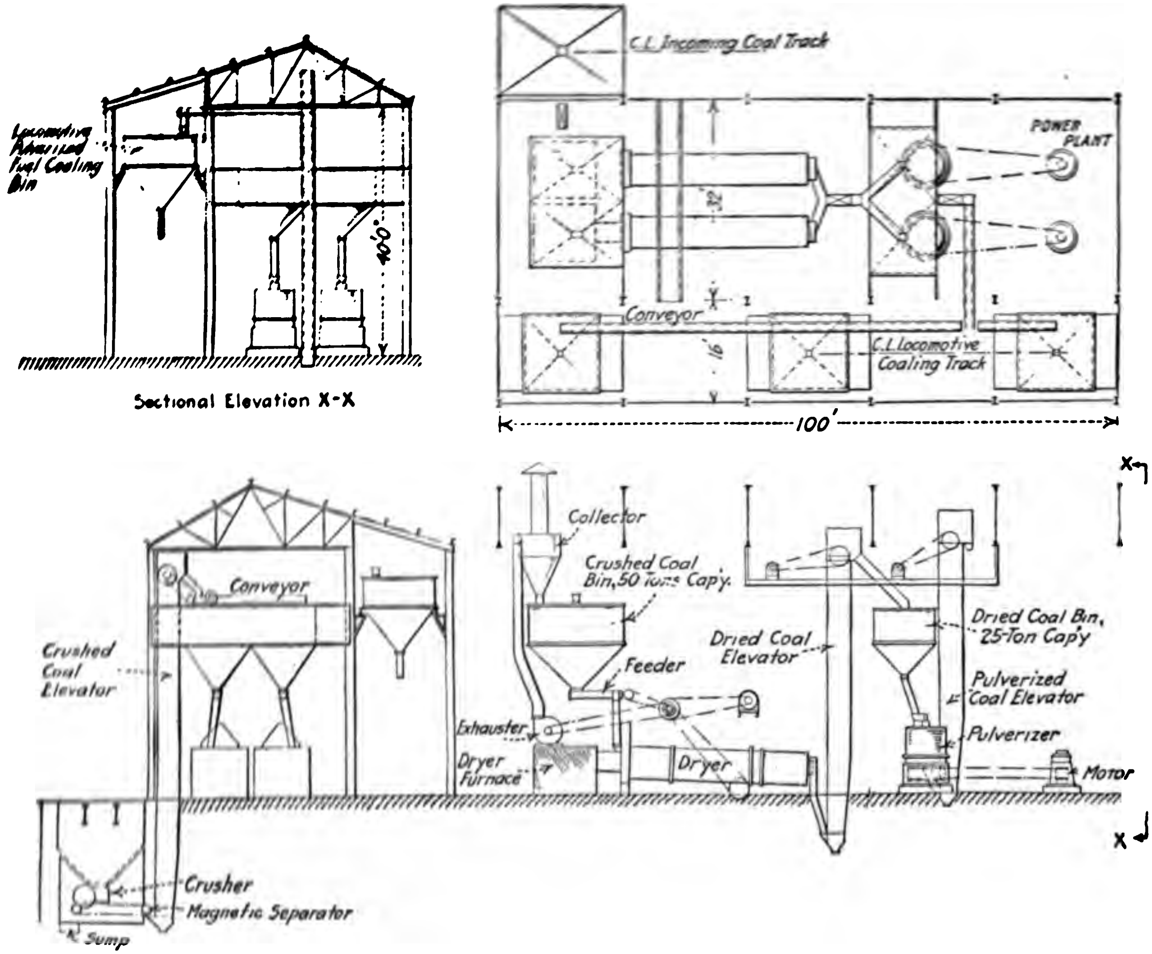


FIG. 68.—Double-unit Plant with Triple-bin for Loading Locomotives. Capacity 16 Tons per Hour.

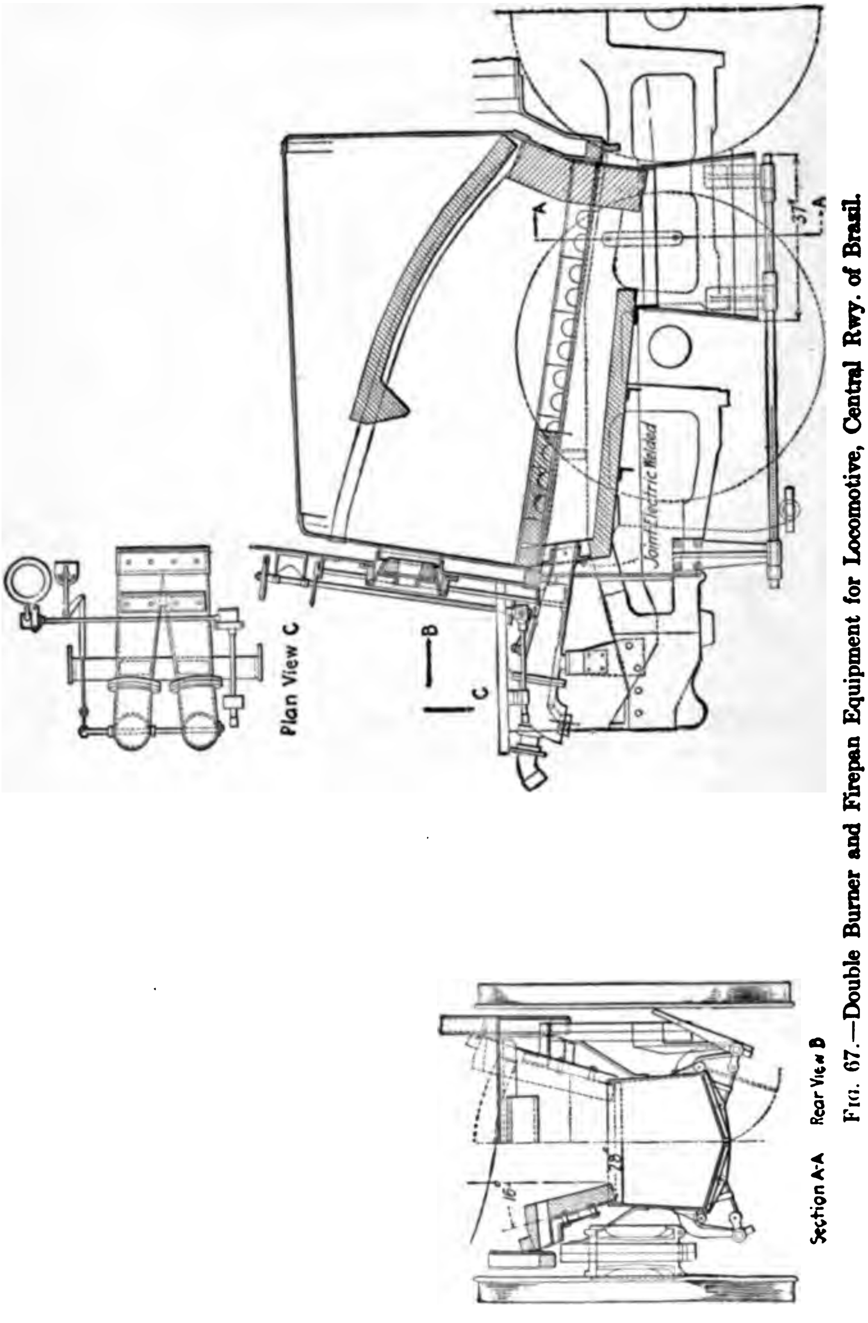


FIG. 67.—Double Burner and Firepan Equipment for Locomotive, Central Rwy. of Brazil.

From forty-five to sixty minutes is ordinarily sufficient to get up 200 lb. of steam pressure from boiler water at 40° F.

After firing up, the regulation of the fuel and air supply is adjusted to suit the standing, drifting or working conditions, the stack blower being used only when the locomotive is not using steam.

The process of feeding and burning powdered coal may be briefly stated as follows: the prepared fuel, having been supplied to the enclosed fuel tank, gravitates to the conveyor screws, which carry it to the fuel and pressure air feeders, where it is thoroughly commingled with and carried by the pressure air through the connecting hose to the fuel and pressure air nozzles and blown into the fuel and air mixers.

Additional air is supplied in the fuel and air mixers; and this mixture, now in combustible form, is drawn into the furnace by the smoke-box draft.

The flame produced when the combustible mixture enters the furnace obtains its average maximum temperature (from 2500 to 2900° F.) at the forward combustion zone under the main arch; and at this point auxiliary air, induced by the smoke-box draft, finally completes the combustion process.

The smoke-box gas analysis will show between 13 and 14 per cent of CO_2, when coal is fired at the rate of 3000 lb. per hour; between 14 and 15 per cent at the rate of 3500 lb. per hour; and between 15 and 16 per cent at the rate of 4000 lb. per hour; so that as the rate of combustion increases, there is no falling off in the efficiency of combustion, as when coarse coal is fired on the grates.

The waste of fuel from the stack, where ordinary coal having a large percentage of dust and slack is used; the lowering of the fire-box temperatures and draft by the opening of the fire door; and the resultant variations in standing and general results under high rates of combustion, are entirely eliminated with powdered coal.

The uniformity with which locomotives

is indicated by the fact that regularly assigned firemen can maintain steam within two pounds of the maximum allowable pressure, without popping off.

As each of the fuel and pressure air feeders has a range in capacity from 500 up to 4000 lb. of powdered coal per hour, and as from one to five of these may be easily applied to the ordinary locomotive tender, there is no difficulty in meeting any desired boiler and superheater capacity.

As in the case of electric locomotives, but little actual operating data are as yet available.

The first complete installations of a fuel-drying and pulverizing plant and locomotive coaling station, in combination with locomotives equipped for burning powdered coal, will be made by the Delaware & Hudson Company and the Missouri, Kansas & Texas Railway, and these are not yet ready for operation. The locomotives so far equipped on other railways are still depending upon the outside or inadequately equipped sources for their supply of powdered coal, which makes the handling somewhat difficult.

Mr. Muhlfeld gives the following record from tests of an Atlantic type passenger locomotive, fired with Kentucky unwashed screenings, 83 per cent of which ran 100-mesh or finer:

LOCOMOTIVE PERFORMANCE

Miles run	171
Running time, hours	3.87
Train, number of cars	5.8
Train, tonnage	291
Speed, miles per hour	44.2
Drawbar pull, pounds	2711
Horse power	319.5
Fuel used, tons	3.82
Water used, gallons	8381
Fuel per horse-power-hour, pounds	6.17
[illegible] horse-power-hour, pounds	56.48
[illegible] per pound of coal, pounds	9.15
[illegible] 212° F., pounds	11.1
[illegible]	77

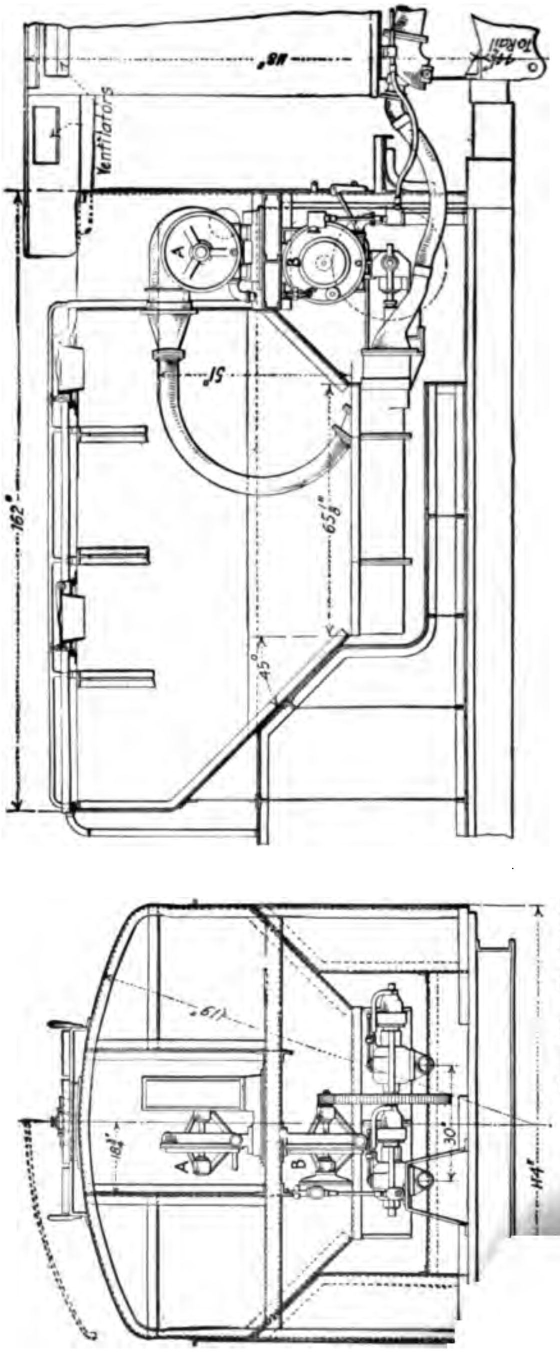


FIG. 68.—Double-Feed Equipment on Locomotive Fender, Central Rwy. of Brazil.

Samples of gas taken from the smoke box gave the results below:

Pounds of Coal Burned per Hr.	Per Cent of		
	CO_2	CO	O
3067	14.5	0.0	4.5
3498	15.2	0.0	2.8
3931	15.2	0.0	4.0
4000	16.4	0.4	2.6

On a 10-wheel locomotive in freight service, three trials gave the results subjoined:

Item.	Pulverized		
	1 Bituminous.	2 Bituminous.	3 Bituminous.
Fineness, per cent through 200-mesh	0.85	0.85	0.85
Moisture, per cent	0.40	0.81	0.59
Volatile, per cent	24.72	36.27	24.36
Fixed carbon, per cent	68.43	58.29	65.05
Ash, per cent	6.85	5.44	10.59
Sulphur, per cent	1.96	0.68	0.84
B.t.u. per pound	14,739	14,334	13,912
Miles run, total	1,324	426	398
Cars per train, average	61	65	60
Adjusted tonnage per train, average	1,719	1,808	1,759
Speed when train was in motion, miles per hour, average	26	25	24
Boiler pressure when using steam (200 lb), average	198.3	193.5	194.9
Front-end draft when using steam, in. of water, average	7.15	7.79	6.69
Firebox draft when using steam, in. of water, average	3.50	3.22	3.18
Temperature of steam, deg. F.	562	573	555
Coal fires per hour of running time, lb. (average)	3,275	3,063	3,457
Adjusted ton-miles per lb. of coal (average)	12.84	13.97	11.59

The locomotive was worked at its maximum capacity on all trips, about 10 per cent more tonnage being hauled than is usual for like locomotives burning coal on grates; and practically at fast-freight schedule speed. The exhaust nozzle opening was about 25 per cent larger than the maximum for hand firing.

The general results were excellent, particularly with
to tonnage, speed, combustion, and steam pressure,
being maintained at full speed with the injector
ximum amount of water to the boiler.
sulphur coal (No. 1) and the highest-

ash coal (No. 3) there was less than 1 cu.ft. of slag in the slag box at the end of each run, and practically no collection of ash or soot on the flue or fire-box sheets. In fact, with the No. 3 fuel there were less than two handfuls of slag, ash and soot collected on each trip.

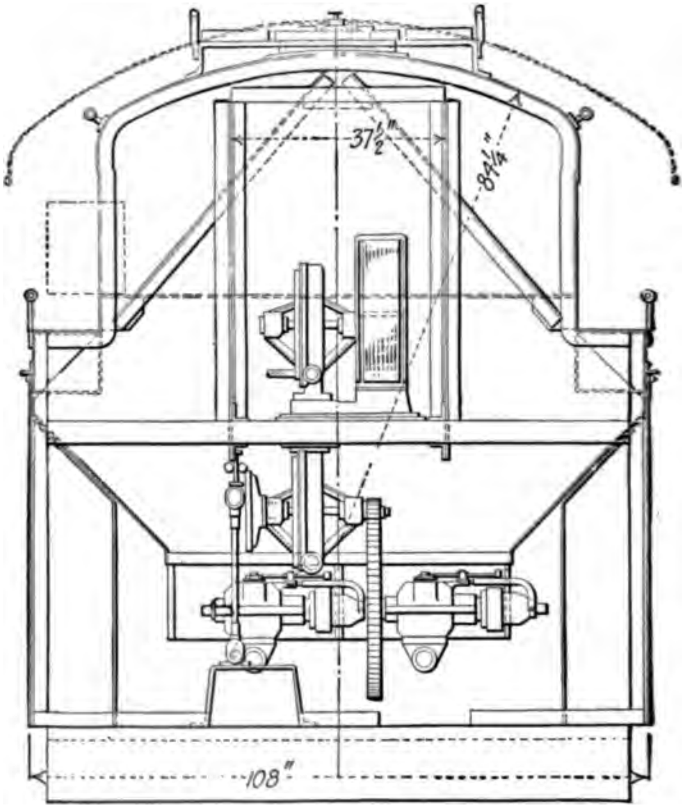


FIG. 69.—Double-Feeder Equipment for Locomotive Fender, N. Y. C. R. R.

Demands upon steam railway motive power to produce increased horse power per hour are becoming more exacting, and there is but little doubt that, through the use of powdered coal in combination with correlated improvements in locomotive design, the steam locomotive can be remain the standard unit of motive power for present and future general railway operation, by reason of its general dependability, flexibility, effectiveness, and economy, and its ability, in a revised form, to meet public demands for the reduction of smoke, soot, cinders, sparks and noise.

CHAPTER X

EXPLOSIONS

Much has been said of the danger of explosions accompanying the use of powdered coal. This is partly due to confusion with dust explosions in coal mines. The latter are due to the floating of dust in the air in a confined space. The department of a powdered coal plant in which the coal grinding is done is usually a fit place for an explosion, for it is almost impossible to grind coal without having some dust escape. There is, on the other hand, plenty of opportunity for change of air, which should minimize the possibility of explosions. Dust is sometimes overcome by the use of a grinding system employing exhaust fans. With the atmosphere saturated with coal dust, and all crevices and ledges filled and covered with fine particles, there would seem to be every chance for an explosion. Yet the author has not heard of an instance where explosions have taken place in the grinding room. There have been cases where a match or spark, coming in contact with some of the dust lying on a ledge, has started a fire which has spread rapidly, but this scarcely constitutes an explosion. The dust acts like a long fuse. The remedy seems to be to keep the grinding room as clean as possible, forbidding the use of any open lights or fire.

During one of the writer's inspection trips special inquiry was made regarding explosions. None had occurred at any of the plants visited. In certain cases the bins overflowed and the falling sheet of coal took fire, but there was nothing that could properly be called an explosion.

Mr. W. D. Wood, in the *Railroad Gazette* of July 18, 1913, says of powdered coal explosions:

" I can say positively that there is absolutely no danger

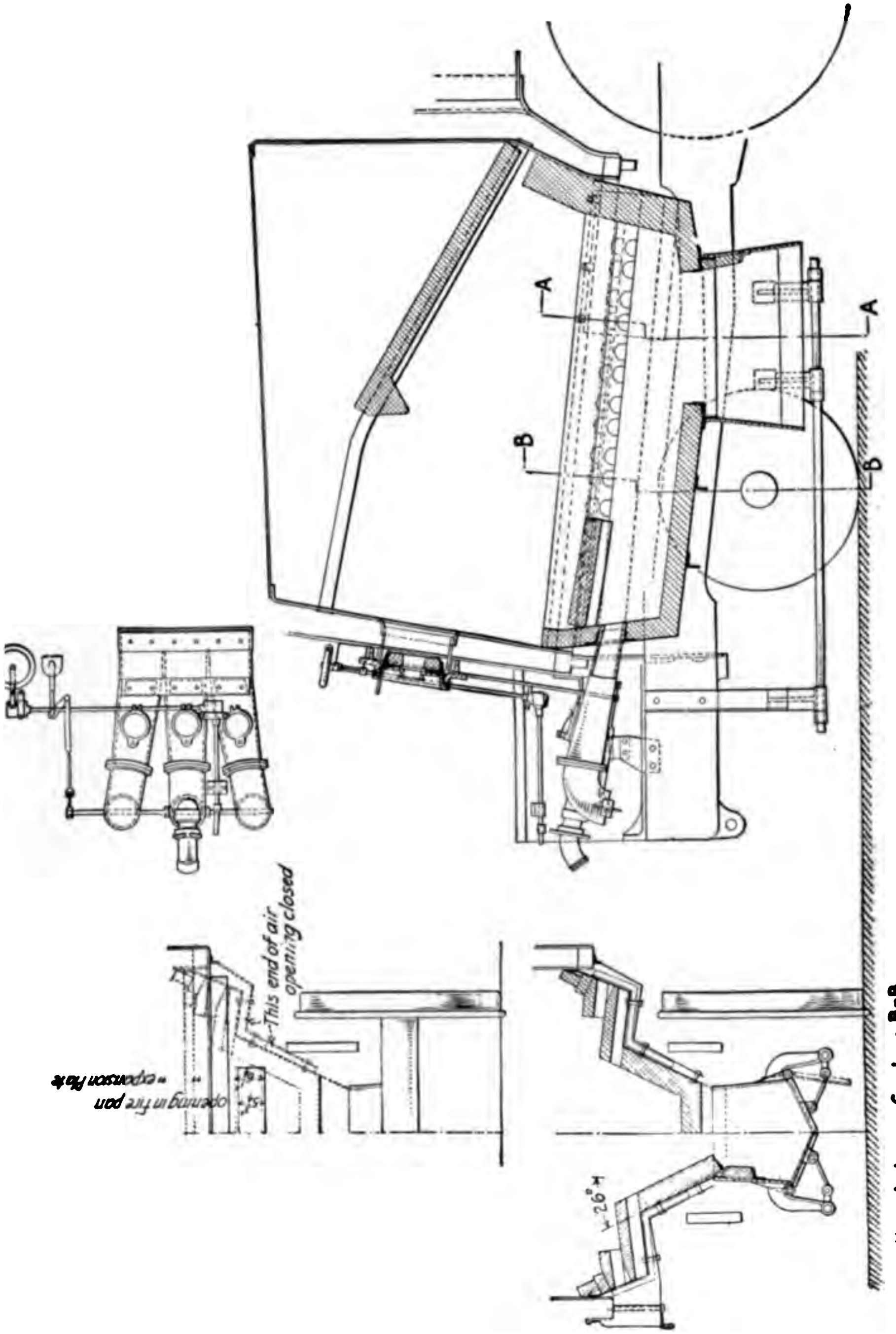


FIG. 70.—Triple Burner and Firepan Equipment for Locomotive. N. Y. C. R. R.

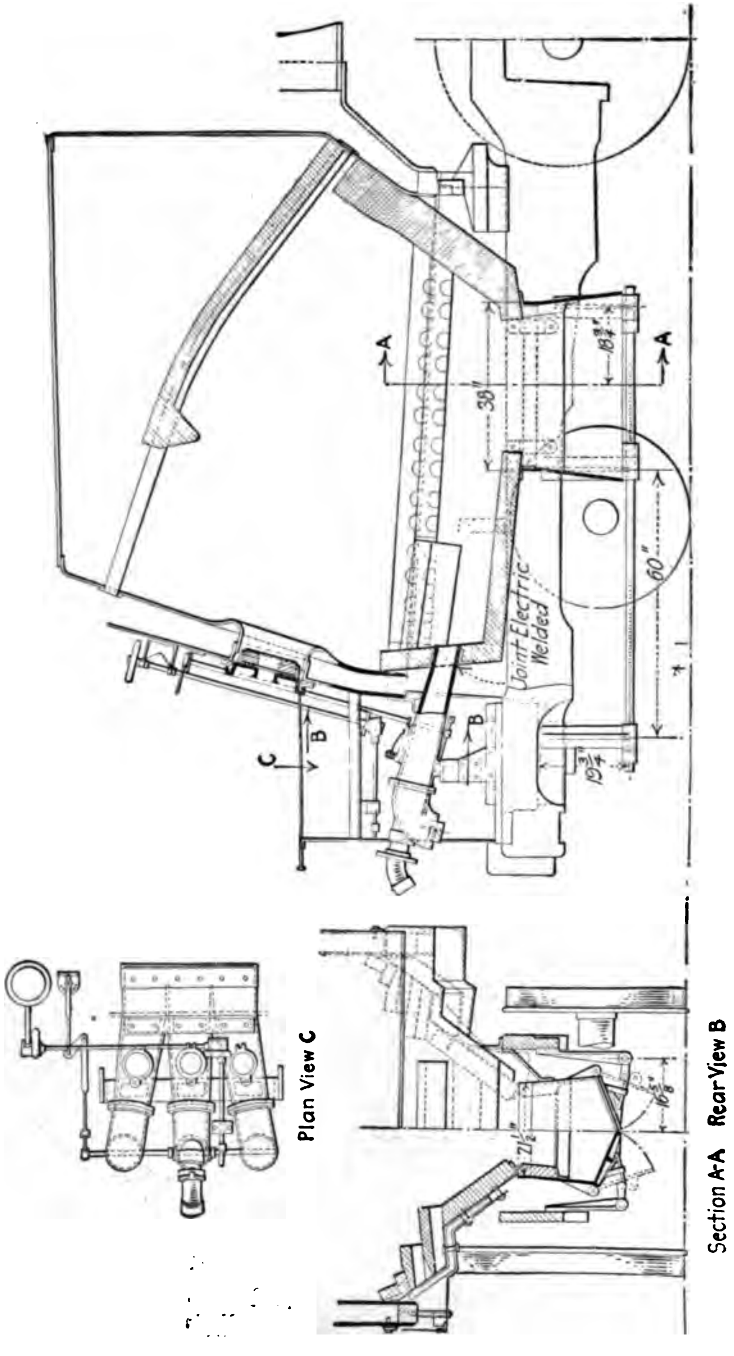


FIG. 71.—Triple Burner and Firepan Equipment for Locomotive. A., T. & S. F. Rwy.

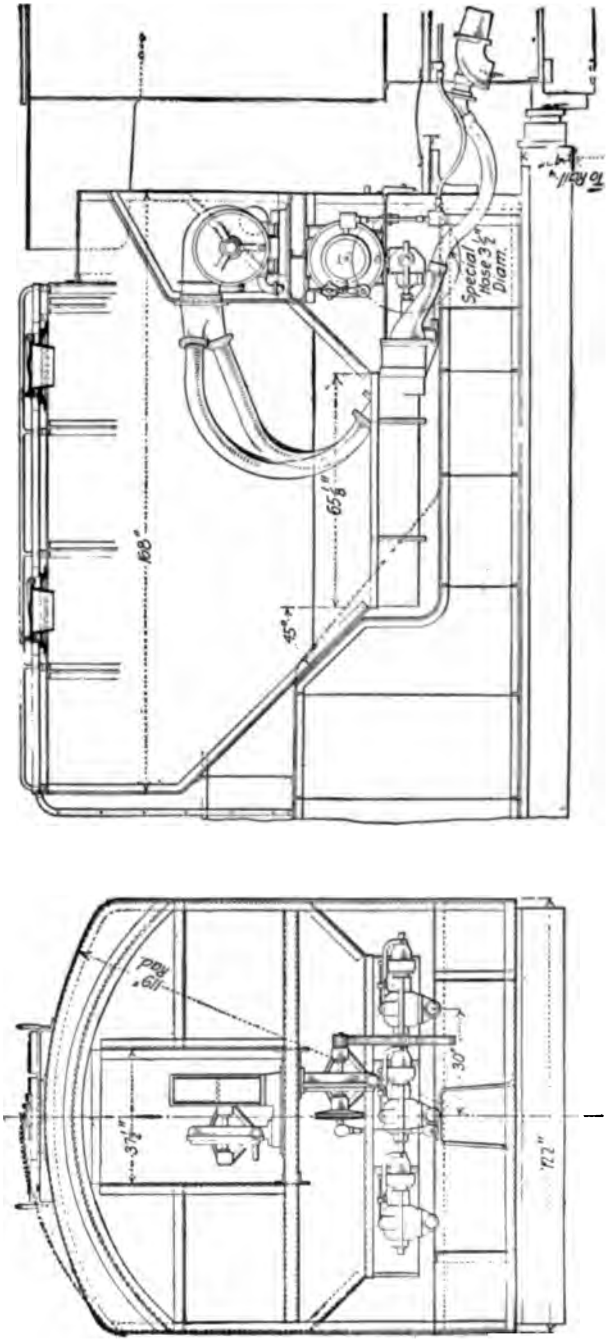


FIG. 72.—Triple Feeder Equipment on Locomotive Fender. A., T. & S. F. Rwy.

of explosions of powdered coal where ordinary sensible precautions are observed. The writer has worked in cement mills, and has burned powdered coal himself, and knows whereof he speaks. In the first place, powdered coal when in storage or in bulk, or while being blown into the furnace, does not explode. It may puff, or flare back slightly, when starting up a fire in a furnace, if there is not enough draft, but even this is preventable. There have been so-called explosions of powdered coal, several of them, but not one person in ten has any idea of what they are like. Several of the large cement companies, including the Atlas, Alpha, Edison, and others, have had explosions, but every one of them to my knowledge has originated in the grinding room where the coal was pulverized. They are sometimes caused by a nail getting in the mill and causing a spark;

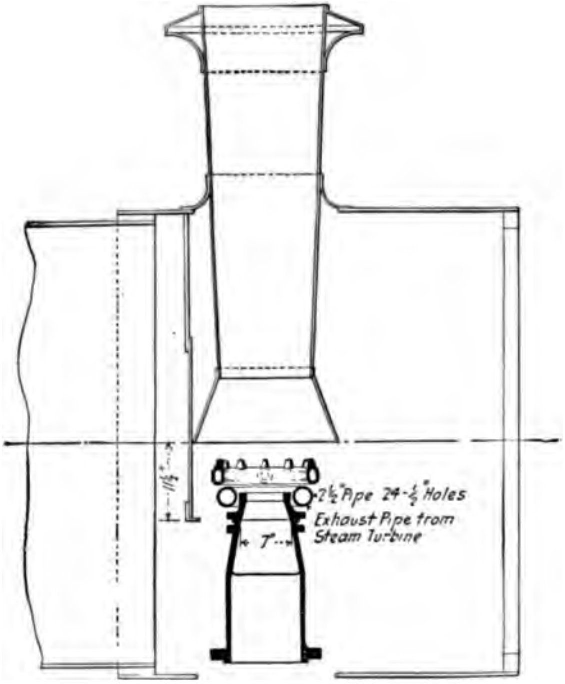
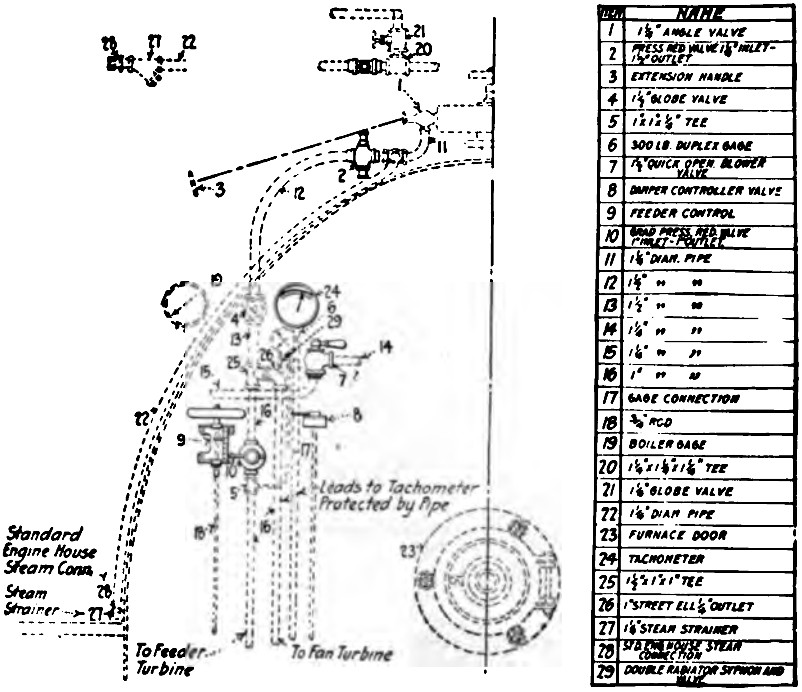


FIG. 73.—Locomotive Front End for Powdered Coal.

and sometimes by the presence of an open flame when cleaning or repairing a mill.

" All of these explosions are caused by impalpably fine dust floating in the air in suspension. This dust floats in layers or strata. Nails and other pieces of iron should be removed by an electro-magnet before the coal goes to the mill, even if only to protect the mill from damage. At a recent explosion (?) in one of the big cement mills the facts were as follows: A foreman and some of his men were repairing and cleaning a mill. One of the men had rammed a piece of waste on the end of a stick into a part he was cleaning and somehow (no one knows how) [illegible] caught fire as he pulled it out. Immediately there was [illegible] hissing sound like a pinwheel going off, or like escaping [illegible]



ITEM	NAME
1	1¼" ANGLE VALVE
2	PRESS RED VALVE 1¼" INLET-1¼" OUTLET
3	EXTENSION HANDLE
4	1¼" GLOBE VALVE
5	1"x1"x¼" TEE
6	300 LB. DUPLEX GAGE
7	1¼" QUICK OPEN. BLOWER VALVE
8	DAMPER CONTROLLER VALVE
9	FEEDER CONTROL
10	GRAD PRESS. RED. VALVE 1" INLET-1" OUTLET
11	1¼" DIAM. PIPE
12	1½" " "
13	1½" " "
14	1¼" " "
15	1¼" " "
16	1" " "
17	GAGE CONNECTION
18	¾" RGD
19	BOILER GAGE
20	1¼"x1¼"x1¼" TEE
21	1¼" GLOBE VALVE
22	1¼" DIAM PIPE
23	FURNACE DOOR
24	TACHOMETER
25	1½"x1"x1" TEE
26	1" STREET ELL ¼" OUTLET
27	1¼" STEAM STRAINER
28	STD. ENG. HOUSE STEAM CONNECTION
29	DOUBLE RADIATOR SYPHON AND VALVE

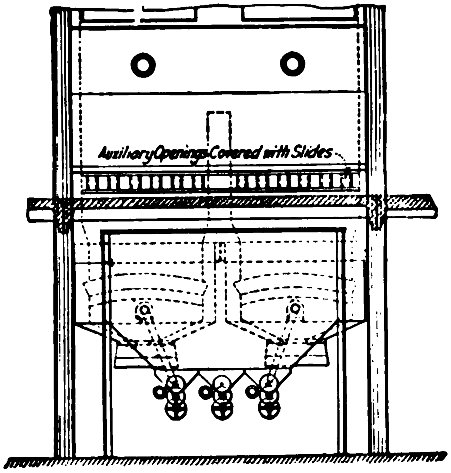
FIG. 74.—Locomotive Cab Equipment for Powdered Coal.

a flash this traveled the length of the room down a stairway, and back several times in layers just like a train of powder, only there was no report, no explosion, just a hissing. The men came out, they were absolutely denuded, yet seemed to retain their faculties. The foreman said " I'm done for and am going to die." He was able to tell what had happened before he became unconscious. They all died shortly afterward.

" As terrible as this seems, it is entirely preventable. I have never seen a cement mill yet where you could go near the pulverizing plant, much less in it, without becoming covered with coal dust. Yet at the American Iron and Steel Manufacturing Co. works at Lebanon, they have used powdered coal for ten years and have never had an explosion. I have stood inside of their grinding room and had a white handkerchief on my sleeve and it caught not a grain of dust.

" Cement mills seem to think that it is cheaper to take chances as long as things keep running rather than to spend enough money for safety. There are two ways to be safe—use a mill that is tight, and spend enough money for competent labor and materials to keep it in repair. As to storage and burning: coal pulverized and stored in tanks is 100 per cent less liable to explosion than oil. It sometimes catches fire from spontaneous combustion or otherwise, and nothing happens any more than what would happen if a pile of slack coal should catch fire. It is not even necessary to shut down. All that is necessary is to keep right on drawing it off in its semi-burnt state, cutting off the supply to the bin that is on fire, and burn it until it is all out of the tank; when a new supply may be put in, if the tank has not become heated. Care must be taken to see that none of the burnt coal remains.

" In a large cement mill, where the writer was employed, it was frequently necessary to walk along the iron gallery in front of the supply bins. This gallery is practically right over the front end of the kilns and only 8 ft. above



Sectional Elevation
A-A

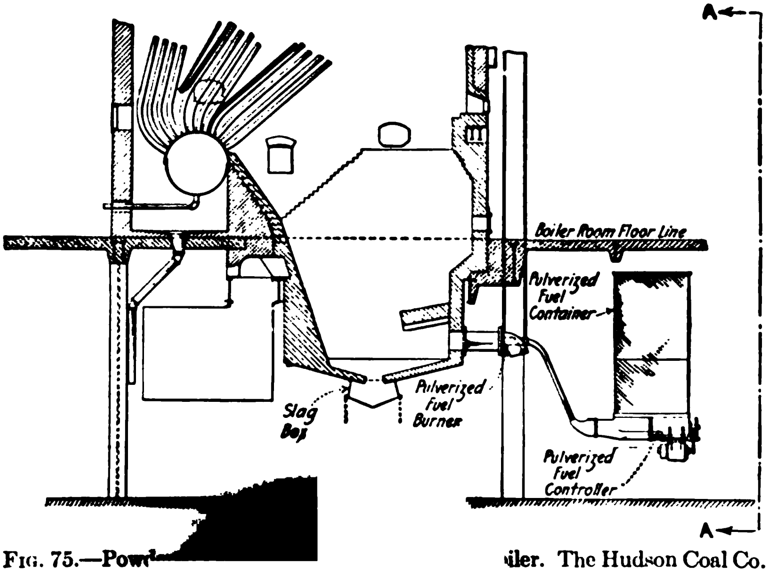


Fig. 75.—Pow[illegible]iler. The Hudson Coal Co.

them. The coal dust which has overflowed the bins is always from 2 to 4 in. thick on this walk. Even when careful (which no one is) a person kicks showers of this fine dust right down over the open red-hot end of the kilns; it is sometimes kicked down over a new man as a joke. Clouds of this dust drift down over the kilns and are sucked in by the draft. Certainly no severer test than this could be applied.

" Powdered coal is as safe as coal in lumps, if common sense and judgment are exercised, and any one who believes the contrary is laboring under a misunderstanding of the facts in the case.

" Open dryers should not be used, that is dryers in which the heat and flame come in direct contact with the coal. This is dangerous and should not be tolerated, though some concerns practice it. There are plenty of good compartment dryers on the market which are safe."

In 1915 Mr. Thomas A. Edison, in explanation of the so-called explosion that took place in his cement mill some years ago made the following statement: " The explosion was occasioned by fine coal dust catching fire and burning slowly in a pit, thus forming an explosive gas with the air. The explosion killed five men. Please let me emphasize the fact that it was not the dust itself that exploded."

Another view of explosions: " With regard to explosions, powdered coal is much safer than oil or natural gas, as a leak is at once detected by the eye, and the trouble can be remedied immediately. The entire system, from the point where the coal is dried, to the bins at the furnaces, may be entirely enclosed, rendering it absolutely dust-tight. The bins and conveying system contain but a small quantity of air; and an explosion there is absolutely impossible in a well-designed plant."

One large company in the central part of New York State, in stating their experience, say " We never had an explosion from the use of powdered coal and we have made extensive experiments with it. We do not consider

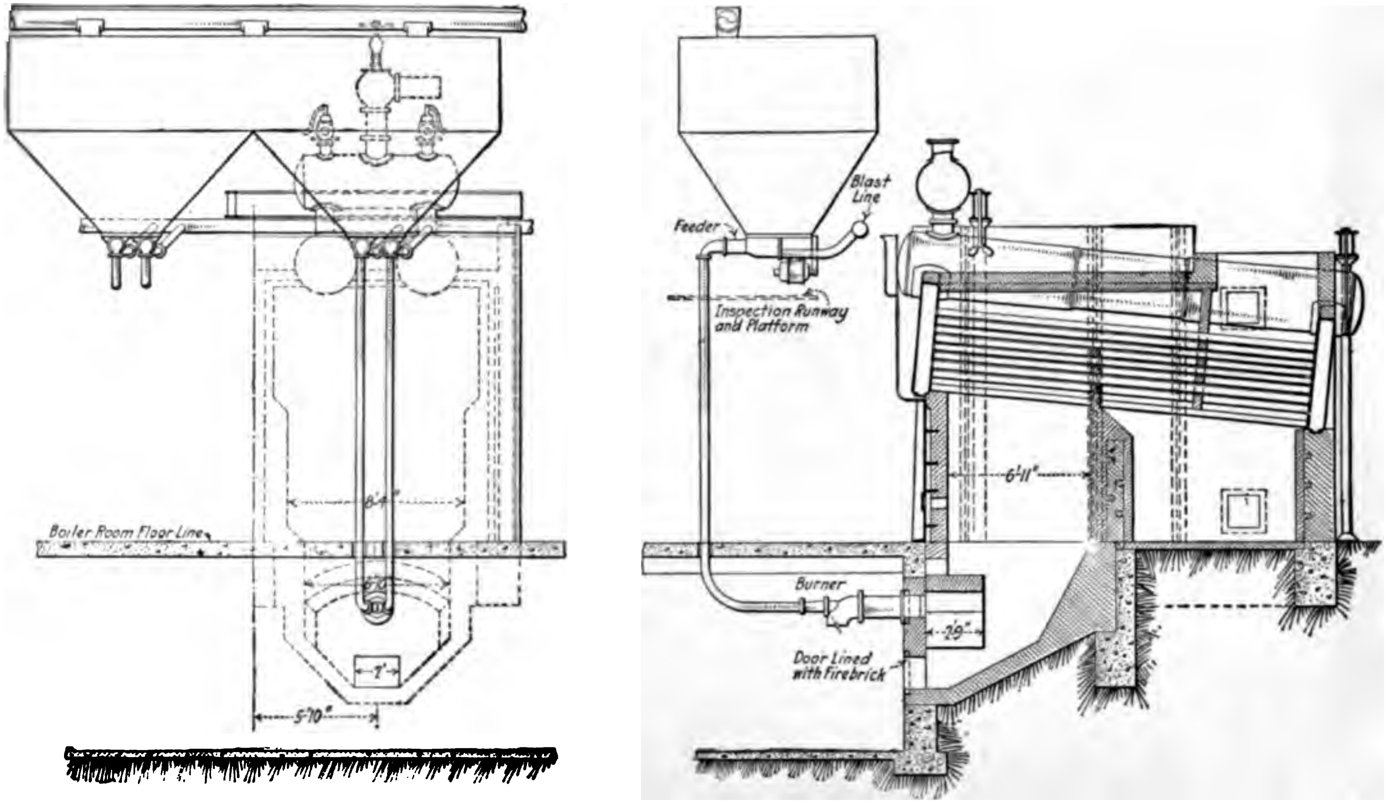


FIG. 76.—Powdered Coal Equipment for O'Brien Boiler. M. K. & T. Rwy.

it advisable to have large quantities of powdered coal lying around."

Storage Difficulties. Storage difficulties should not exist with dry coal. There should be no floating dust in the atmosphere. Moist coal should not be stored as it does not flow freely, but cakes up and gives trouble. Provision should be made for keeping the coal moving, and in case of shut-down of plant, coal should not be left in the storage bins for much over a week. These are the only precautions which it is necessary to take. No trouble is experienced from the storage of coal for short periods of time. It should be given a chance to cool between the pulverizing machine and the storage bin.

The caking of coal dust in separate bins at each furnace was the cause of a fire at the Burden Iron Works about two years ago. The coal persisted in caking and the men were in the habit of using a club to hammer the sides of the bins in order to get the coal dust to flow into the controller, until the point was reached where the bins were getting so damaged that the manager had to forbid hammering. Then one night one of the men, trying to get coal dust, removed the slide at the bottom of the bin between it and the controller, thinking no doubt that the coal would then move more freely, with the result that the coal dust leaked in small particles down on to the floor. There was a strong wind blowing at the time, and just at the moment when the operator was taking out a heat, a puff of wind blew some of the coal dust across the heat with the result that it instantly took fire. The conditions here were ideal for combustion.

It was a coincidence that just above this furnace the shop was divided into two parts, the old one having a roof of wood trusses and the new part one of steel trusses. The flame shot up instantly to the wood trusses and as they were covered with fine particles of powdered coal the fire swept across these trusses and inside of ten minutes the roof was a furnace and the men had to flee for their lives. The fire burned from 10 P.M. to 2 A.M., when the roof all caved in

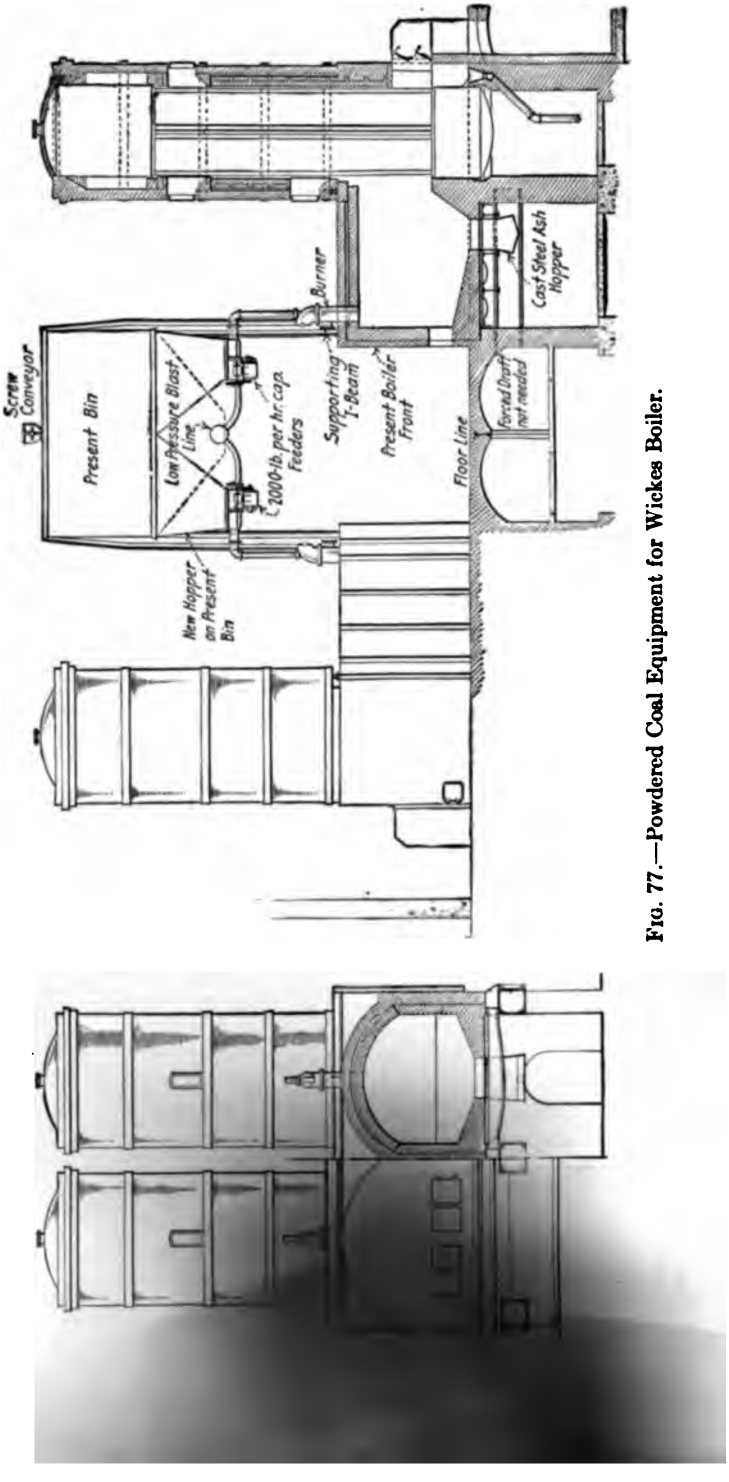


Fig. 77.—Powdered Coal Equipment for Wickes Boiler.

and fell on the furnaces. That part of the building having the steel trusses did not catch fire, thanks to the efforts of the firemen. The measuring hoppers and screw conveyors, with walkways, came down with the roof, but there was no back flash of coal dust through the conveyors, nor was there any explosion of coal dust. It was simply a fire caused by the existence of perfect conditions for combustion.

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